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GRAND (NEOSHO) RIVER INVESTIGATION (KANSAS, OKLAHOMA, MISSOURI, ARKANSAS)

Mark D. Hollis, et al

Public Health Service
Cincinnati, Ohio

August 1940

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UNITED STATES PUBLIC HEALTH SERVICE
OFFICE OF STREAM SANITATION
CINCINNATI, OHIO.
AUGUST, 1940

GRAND (NEOSHO) RIVER INVESTIGATION

KANSAS, OKLAHOMA, MISSOURI, ARKANSAS

A STUDY OF PUBLIC WATER SUPPLY AND STREAM POLLUTION IN THE GRAND (NEOSHO) RIVER BASIN AND THE NEED AND JUSTIFICATION FOR LOW FLOW REGULATION FROM CONSERVATION STORAGE IN PROPOSED FLOOD CONTROL RESERVOIRS.

PREPARED UNDER THE DIRECTION OF
ASSOCIATE PUBLIC HEALTH ENGINEER MARK D. HOLLIS
U. S. PUBLIC HEALTH SERVICE

AT THE REQUEST OF
THE CHIEF OF ENGINEERS
UNITED STATES ARMY

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United States Public Health Service
Office of Stream Sanitation
Cincinnati, Ohio
August 1940

GRAND (NEOSHO) RIVER INVESTIGATION

(Kansas, Oklahoma, Missouri, Arkansas)

By

Mark D. Hollis, Associate Public Health Engineer
Richard L. Woodward, Assistant Public Health Engineer
Sam R. Weibel, Assistant Public Health Engineer
Paul D. Haney, Assistant Sanitary Engineer (R)

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Authority & Procedure

The Grand (Neosho) River investigation, reported herein, was directed by the Surgeon General of the United States Public Health Service, under date of January 22, 1940, in response to a request, dated January 16, 1940, from the Chief of Engineers, United States Army, Washington, D. C.

Expenditures for the investigation were made from funds allocated by the War Department to the Public Health Service for the Ohio River Pollution Survey. Reimbursement, in the manner prescribed by federal statutes, is to be made from War Department funds allotted to the District Engineer, U. S. Engineer Office, Tulsa, Oklahoma for studies of flood control on the Grand (Neosho) River.

Preliminary conferences to outline the scope, policies, and procedures of the investigation were held with the Kansas State Health Commissioner at Topeka, and the State Sanitary Engineer at Lawrence on April 30, 1940. The State Health Departments of Oklahoma, Missouri, and Arkansas were also contacted. On May 1, 1940, detailed procedures were discussed with the District Engineer, U. S. Engineer Office, in Tulsa, Oklahoma.

The investigation of the Grand (Neosho) River was primarily to correlate public water supply usage and stream pollution abatement with the flood control program as proposed by the War Department. The five specific problems covered by the investigation, as propounded by the U. S. Engineer Department, are:

(I) Determine what possible alternate sources of public water supply are available to towns now dependent on the Grand (Neosho) River, with special attention to the possibility of developing satisfactory supplies from underground sources.

(II) Determine the relative merits of the proposed reservoirs on the upper Cottonwood and Grand (Neosho) Rivers as sources of public water supply from a standpoint of chemical, bacterial, and biological quality.

(III) Considering the maximum conservation storage in the Council Grove and Marion reservoirs at 47,000 and 27,500 acre-feet respectively, determine the adequacy of these storage capacities for pollution abatement and water supply use and the desirable rates of release for these purposes.

(IV) Determine the estimated monetary value of water stored in these reservoirs for pollution abatement and municipal water supply purposes.

(V) Determine the significance of stream pollution in the Spring and Elk (Cow Skin) River basins, practical control measures, and the value of conservation storage in the Waco and Neel reservoirs for pollution correction.

The investigation was under the administrative supervision of the Office of Stream Sanitation, U. S. Public Health Service, Cincinnati, Ohio. Associate Public Health Engineer Mark D. Hollis, who directed preparation of the report, was in immediate charge of the field work with temporary headquarters at Lawrence, Kansas.

Personnel for the investigation were Richard L. Woodward and Sam. R. Weibel, Assistant Public Health Engineers, and Paul D. Haney, Assistant Sanitary Engineer (R), all temporarily detached from the Ohio River Pollution Survey. The U. S. Engineer Office at Tulsa assigned Junior Engineer J. A. Bader, and two engineering aids to assist with sampling schedules and collection of field data. The employment of a sanitary chemist and a stenographer was also authorized. Field headquarters at Lawrence were with the Division of Sanitation, State Board of Health, in space provided by the School of Engineering, University of Kansas.

Intensive field and laboratory investigations were conducted during the 4-week period May 20-June 17, 1940. Collection of field data was in collaboration with the several state health departments. The excellent water and sewage laboratory facilities of the Kansas State

Board of Health at Lawrence were utilized for all analytical determinations. Due to high river stages, laboratory observations of actual stream conditions were of little value in the determination of probable behavior at critical flows.

All hydrometric data used in analyzing the problems were secured from the District Engineer, U. S. Engineer Office at Tulsa, Oklahoma.

In assembling data, splendid cooperation was received from federal and state agencies, municipal officials and industry. Special acknowledgment is due the U. S. Engineer Office at Tulsa, Oklahoma, and the Kansas State Board of Health, through whose efforts the investigation was made possible; to the Engineering School, University of Kansas, for providing office space; to the state health departments of Oklahoma, Missouri and Arkansas for file data and assistance with field contacts; to the Tri-State Zinc and Lead Ore Producers Association for assistance in the metal mine waste pollution problem; and to the following agencies for making file data available for reference:

Board of Agriculture, Div. of Water Resources,
Topeka, Kan.

State Geologist, University of Kansas, Lawrence, Kan.

U. S. Bureau of Mines, Bartlesville, Okla.

Dairy Commissioner, Kansas Board of Agriculture, Topeka.

Kansas Fish and Game Division, Pratt, Kansas

Mine Inspection Div., Kansas State Labor Department

Kansas Geological Survey, Lawrence, Kansas

United States Weather Bureau, Topeka, Kansas

United States Geological Survey

State Planning Boards of Kansas, Oklahoma, and Missouri.

Syllabus and Summary of Conclusions

Syllabus

Investigation of the Grand (Neosho) River was primarily to correlate the need, value, and effect of conservation storage in proposed flood control reservoirs with public water supply use and stream pollution control. Locally, there is definite need and demand for low flow control, and this demand can be met most equitably by flow regulation from conservation storage in proposed flood control reservoirs. Optimum conservation storage as proposed at Council Grove and Marion is theoretically sufficient for minimum water supply and dilution requirements. However, a more satisfactory solution to the water use program may be implemented with a small regulatory pool in the proposed Iola reservoir. With flow regulation at Iola, conservation storage in Council Grove could be materially reduced. Municipalities along the Grand (Neosho) River are mainly dependent on surface streams as sources of water supply. Of the two headwater impoundments, releases from Council Grove would be of preferable quality. Only slight justification from a water supply and pollution standpoint can be shown for provision of conservation storage in the proposed Waco and Pool reservoirs.

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In regards low flow control, only minimum economic benefits are invoicable in dollars. Major benefits accruing from proposed flow regulation are classified as intangibles. Although no monetary figures are expressed for intangibles, it is opinioned that the value of intangible benefits might well equal or exceed the indicated tangible benefits.

Metal mine wastes tributary to the Spring River were found to have a bearing on stream conditions. Most promising methods of acid waste control involve neutralization in off-channel precipitation impoundments.

Summary of Conclusions

(1) Surface waters are the only satisfactory source of public water supply in the Kansas portion of the Grand (Neosho) River basin, with the possible exception of the extreme southeastern area. Available underground waters are limited in quantity and are highly mineralized.

(2) Chemically and biologically, impounded storage in the Council Grove reservoir on the upper Neosho River will be preferable to an impoundment at Marion on the Cottonwood.

(3) In the Grand (Neosho) River organic pollution control by stream regulation from conservation storage should be combined with secondary treatment of organic waste prior to discharge. It is infeasible to provide sufficient stream flow properly to dilute oil field wastes in the quantities produced.

(4) Low flow augmentation from proposed conservation storage in the Marion and Council Grove reservoirs appears sufficient for minimum public water supply and

organic pollution control, provided effluent wastes receive secondary treatment prior to discharge. With the Marion-Council Grove reservoir system, recommended seasonal releases are:

	Marion	Council Grove
December - May	0 c.f.s.	10 c.f.s.
June - September	20 "	30 "
October - November	10 "	10 "

(5) With regulation from 10,000 acre-feet conservation storage in the Iola flood control reservoir, a minimum flow of 50 c.f.s. could be maintained below Iola. This release would reduce the uncertainties of maximum water use under the aforementioned system (4), which use is dependent on times of flow and reservoir release synchronization. It would also increase waste dilution ratios, and improve chemical quality of downstream water supplies. With Iola regulation conservation storage in the Council Grove reservoir could be reduced to 20,000 acre-feet, representing storage sufficient to provide a minimum release of 10 c.f.s.

(6) The minimum tangible monetary values of conservation storage for water supply use and pollution control are computed to be $35.00 per acre-foot for the Marion-Council Grove reservoir system, and $45.00 per acre-foot for the Marion-Council Grove-Iola reservoir system.

(7) Extreme paucity of long range data necessitated considering as intangibles major benefits from flow regulation. Of special significance are indeterminate values to public health, aquatic and wild life, recreation, agricultural uses, and improved chemical qualities. Although not mathematically substantiated, it is opinioned that intangible benefits might well equal the computed tangible benefits (Paragraph 6).

(8) Significant pollution of the upper Spring River and its tributaries results from discharge of improperly treated sewage and organic industrial wastes. The lower reaches are polluted by acid wastes from coal and metal mines. No significant pollution problem exists in the Elk (Cow Skin) River.

(9) Organic pollution in the Spring River can be effectively controlled by practical waste treatment methods, but no entirely satisfactory means for treating metal mine wastes has yet been developed. In general, promising corrective measures involve acid neutralization by the use of either chemicals or natural stream alkalinity with precipitation of iron and aluminum in off-channel impoundments.

(10) Low flow regulation from the Waco Reservoir would have no appreciable effect on organic pollution or coal mine drainage. However, low flow control may prove beneficial in the treatment of metal mine wastes involving use of natural stream alkalinity. Beneficial use would be dependent on minimizing the diurnal fluctuation in river stages below the Lowell power dam.

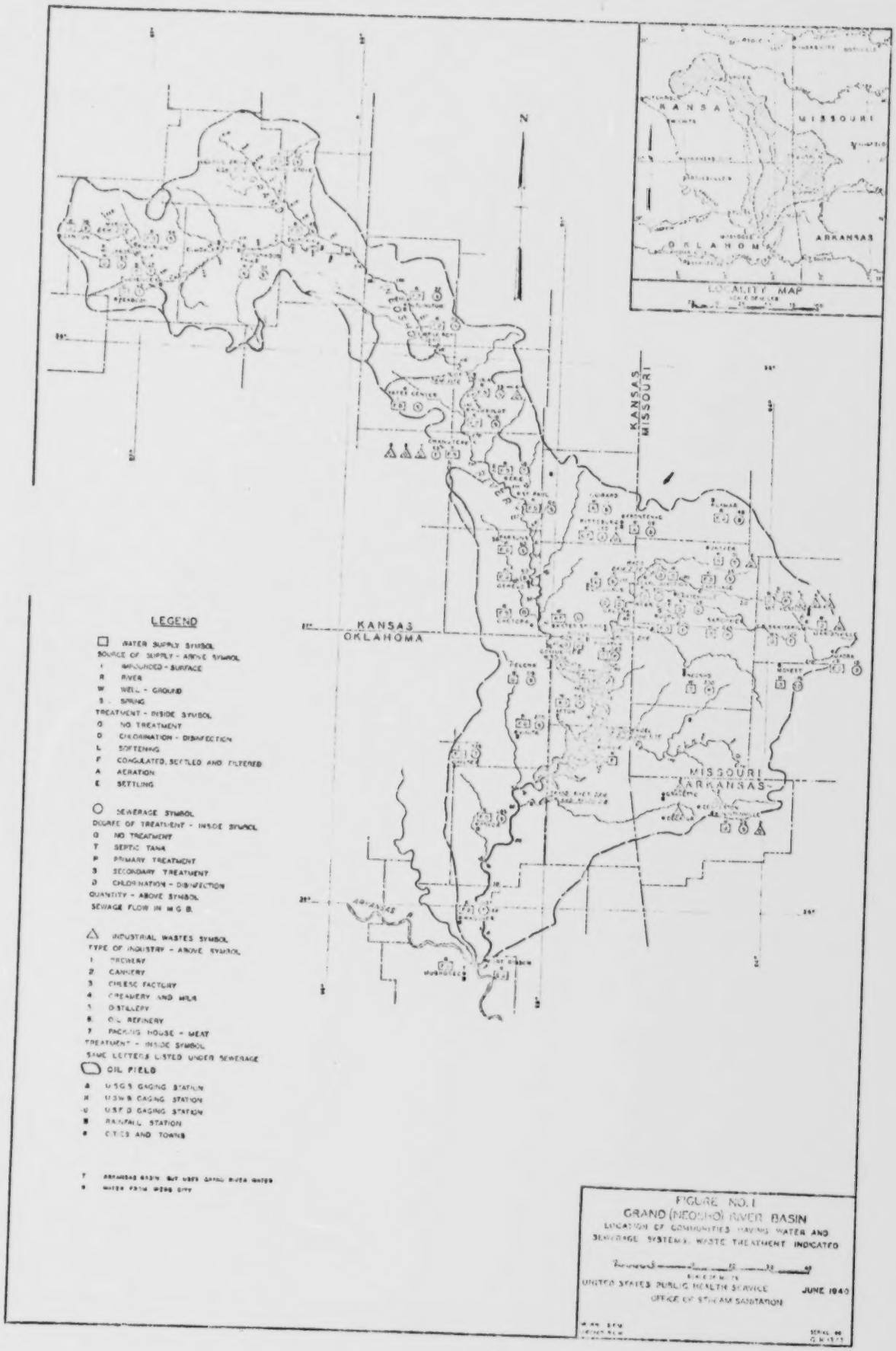

FIGURE NO. 1
GRAND (NEOSHO) RIVER BASIN
LOCATION OF COMMUNITIES HAVING WATER AND SEWERAGE SYSTEMS, WASTE TREATMENT INDICATED

UNITED STATES PUBLIC HEALTH SERVICE JUNE 1940
OFFICE OF STREAM SANITATION

SECTION ONE

The Grand (Neosho) River Basin

(A) Physical Background Data

(1) Description

The Neosho River, known as the Grand below the Spring River confluence (mile 131)*, rises in the Flint Hills region in Morris County, east central Kansas (mile 478) some 20 miles east of the 97th meridian, and flows southeasterly 314 miles in Kansas, thence southerly about 164 miles across northeastern Oklahoma to its junction with the Arkansas River near Fort Gibson, Oklahoma. The Grand (Neosho) River, 478 miles in length, drains approximately 12,660 square miles, of which 6,285, or 50%, lies in Kansas, 2,965, or 23.5% in Oklahoma, 2,995 representing 23.5% in Missouri, and 415 square miles, or about 3% in Arkansas.

The watershed outline of the Grand (Neosho) River and principal tributaries is shown in Figure 1, together with information on public water supplies and sources of organic and oil field pollution. The headwater reach of the watershed has a width of about 30 miles, in-

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* River miles above the mouth.

creasing to about 80 miles to include the basin of the Cottonwood River (mile 383), which extends westward beyond the 97th meridian. From the Cottonwood River confluence downstream to St. Paul, Kansas, the watershed varies from 16 to 30 miles in width. Below that point the basin again broadens to embrace the basins of the Spring and Elk Rivers, reaching a maximum of 90 miles near the Kansas-Oklahoma state line (mile 164), then decreases in width downstream from that locality to the confluence with the Arkansas River.

The watershed is bounded by the basins of the Kansas and Osage Rivers on the north, the White and Illinois Rivers on the east, and the Verdigris River on the west.

The elevation above mean sea level of the headwaters in Kansas is about 1,450 feet, and at the mouth about 475 feet.

The Grand (Neosho) River and its tributaries are considered as non-navigable streams. In its 478 mile course the river falls about 1,000 feet, representing an average of approximately 2 feet per mile. The low water gradient decreases from about 8 feet per mile in the headwaters to about 2.3 feet per mile at the mouth of the Cottonwood River (mile 383). From there to the mouth of

the Spring River (mile 130) the average fall is 1.4 feet per mile. Below the mouth of Spring River the gradient increases to about 1.8 feet per mile. The well defined stream channel varies in width from 100 to 400 feet and is occasionally obstructed by snags, wrack heaps, and gravel bars. Throughout its course the river occupies a bed of gravel, boulders, and rock ledges that is generally permanent. At low flows the river channel is a succession of pools and shoals.

The stream carries comparatively small amounts of silt. The banks of the stream are generally stable, vary in height from 15 to 30 feet, and support a relatively good growth of oak-pine timber and brush above the low water line. The river valley varies from 1 to 4 miles in width.

(2) Tributaries

Table 1 shows the drainage areas, lengths, widths and slopes of the larger tributaries of the Grand (Neosho) River.

The three principal tributaries, the Spring, Cottonwood and Elk Rivers, drain more than 50% of the total watershed area. Below the Cottonwood River for approximately 200 river miles, no notable tributaries

enter the stream and the watershed area is increased by only 2,280 square miles. In general, the tributaries have physical characteristics similar to those of the main stem.

Table 1 Principal Grand (Neosho) River Tributaries with Salient Features as to Drainage, Dimensions and Slopes.

Tributary and River Mi. No.	Drainage Area (sq.mi.)	Approx. Length Tributary (Miles)	Dimensions of Basin		Low Water Slope (ft/mi)
			Length (Mi.)	Ave. Width (Miles)	
Pryor Cr. (40)	270	42	34	8	-
Spavinaw Cr. (61)	400	60	46	9	-
Cabin Cr. (68)	490	40	35	14	-
Elk River (114)	1,015	80	48	21	10.3
Spring R. (131)	2,655	120	60	45	5
Labette Cr. (171)	391	46	37	11	3
Lightning Cr.(185)	234	51	34	7	-
Flat Rock Cr.(231)	153	21	17	9	-
Cottonwood R.(383)	1,830	157	70	26	3.2

(3) Topography & Geology

The topography of the Grand (Neosho) River varies from a rolling to a rough hill country. The extreme eastern portion of the watershed in Missouri, Oklahoma and Arkansas is located in the rough terrain of the Boston Mountains of the Ozark uplift. Rolling uplands about 150 feet above and 1 to 5 miles from the river characterize the valley in Kansas and on the right bank in Oklahoma. These uplands have a rather steep slope

towards the valley proper, thereby providing rapid runoff for the tributary streams. A light top soil covering on these uplands provides good grass and substantial portions of this area are devoted to grazing. Timber growths are quite abundant in the Boston Mountains but on the remainder of the watershed the growth is confined almost exclusively to the stream banks. Few swampy areas and no natural lakes exist in the basin.

Outcroppings predominantly of limestones, shales, and some sandstone are found in Kansas. The Flint Hills, a prominent escarpment of flint-bearing limestone, run north to south in the upper reaches of the basin in Kansas. The underlying formations in this area are essentially of the Permian and Pennsylvanian periods and lie in long, flat belts underlain with shale. There are very few major structural deformations in these formations. In the eastern portion, the tributaries have cut deeply into the Boone limestone and the Mississippian Chattanooga shale on the western flank of the Ozark uplift. The rocks in this portion have been faulted and folded and principally in the Boone limestone some underground drainage systems and caverns have been developed. The stream channel in Oklahoma is characterized by an abundance of cherty limestone.

(4) Population

Based on Federal census statistics, the total population of the Grand (Neosho) River basin in 1930 was about 493,000, of which 171,000, or about 34% resided in urban (above 2500) communities. Comparison of population figures for 1920 and 1930 indicates a slight decrease in both rural and urban areas during that decade. Because of economic conditions and droughts a similar trend has probably prevailed subsequent to the 1930 census. Joplin, Missouri and Pittsburg, Kansas, with 33,454 and 18,145 inhabitants, respectively, are the largest cities in the basin.

Pertinent data on population trends in the Grand (Neosho) River basin for 1920-1930 census years, by states and watershed divisions, are shown in Table 2. Population trends for principal basin cities are indicated in Table 3.

(B) Hydrology

(1) Precipitation

The normal annual precipitation over the Grand (Neosho) Basin, as determined from the Standard U. S. Weather Bureau 35-year mean, is approximately 40 inches, varying from about 31 inches in the headwater area to

Table 2 Population of Grand (Neosho) Basin by States and Tributary Basins.

State or Division	Drainage Area Sq. Mi.	1920	1930	Density 1930
Kansas	6,285	241,000	224,200	35.6
Oklahoma	2,965	156,300	153,900	52.9
Missouri	2,995	104,500	100,600	33.5
Arkansas	415	15,200	14,100	33.9
Totals	12,660	517,000	492,800	39.0
Neosho River (Kan)	6,120	220,000	203,400	33.2
Spring River	2,655	188,800	182,400	68.8
Elk River	1,015	27,500	27,000	26.5
Grand River (Okla)	2,870	80,700	80,000	27.9
Totals	12,660	517,000	492,800	39.0

Table 3 Population Trends of Principal Cities in the Grand (Neosho) Basin.

City or town	County	State	Population. 1910	1920	1930
Burlington	Coffey	Kansas	2,180	2,236	2,273
Chanute	Neosho	"	9,272	10,286	10,277
Columbus	Cherokee	"	3,064	3,235	3,155
Council Grove	Morris	"	2,545	2,857	2,898
Emporia	Lyon	"	9,058	11,273	14,067
Frontenac	Crawford	"	3,396	3,225	2,085
Galena	Cherokee	"	6,096	4,712	4,736
Girard	Crawford	"	2,446	3,161	2,442
Humboldt	Allen	"	2,548	2,525	2,558
Iola	"	"	9,032	8,513	7,160
Oswego	Labette	"	2,317	2,386	1,845
Parsons	"	"	12,463	16,028	14,903
Pittsburg	Crawford	"	14,755	18,052	18,145
Aurora	Lawrence	Mo.	4,148	3,575	3,875
Carterville	Jasper	"	4,539	2,434	1,600
Carthage	"	"	9,483	10,068	9,736
Joplin	"	"	32,073	29,902	33,454
Monett	Barry	"	4,177	4,206	4,099
Neosho	Newton	"	3,661	3,968	4,485
Webb City	Jasper	"	11,817	7,807	6,876
Cardin	Ottawa	Okla.	- -	2,640	437
Commerce	"	"	- -	2,555	2,608
Miami	"	"	2,907	6,802	8,064
Picher	"	"	- -	9,676	7,773
Vinita	Craig	"	4,082	5,010	4,263
Wagoner	Wagoner	"	4,018	3,436	2,994

Table 4 Monthly Distribution of Normal Annual Rainfall in the Grand (Neosho) River Watershed. (From data by U. S. Engineer Office, Tulsa, Okla.)

Month	Missouri and Arkansas		Oklahoma		Kansas		Total	
	Inches	Percent	Inches	Percent	Inches	Percent	Inches	Percent
Jan.	2.32	5.21	2.49	5.71	1.18	3.21	1.79	4.43
Feb.	1.77	3.98	1.78	4.08	1.47	3.99	1.62	4.01
Mar.	3.46	7.77	3.21	7.36	2.36	6.41	2.85	7.05
Apr.	4.52	10.15	4.37	10.02	3.69	10.03	4.07	10.06
May	5.40	12.13	5.06	11.61	4.87	13.23	5.05	12.49
June	5.65	12.69	5.42	12.43	5.14	13.96	5.34	13.20
July	4.36	9.79	3.90	8.95	3.86	10.49	4.00	9.89
Aug.	4.21	9.46	3.88	8.90	3.79	10.30	3.92	9.69
Sep.	4.05	9.10	4.17	9.56	3.99	10.84	4.05	10.01
Oct.	3.70	8.31	4.11	9.43	3.06	8.31	3.48	8.61
Nov.	2.95	6.63	2.94	6.74	2.10	5.70	2.52	6.23
Dec.	2.13	4.78	2.27	5.21	1.30	3.53	1.75	4.33
Annual	44.52	100.00	43.60	100.00	36.81	100.00	40.44	100.00

Table 5 Monthly Average Temperature Data in Degrees Fahrenheit, for various sections of the Grand (Neosho) River Basin.

Month	Missouri and Arkansas	Oklahoma	Kansas	Total
Jan.	34.6	36.8	32.1	33.9
Feb.	37.1	41.6	35.7	37.5
Mar.	47.4	49.7	45.5	47.0
Apr.	57.2	59.6	56.2	57.3
May	65.4	67.2	64.9	65.6
June	73.4	75.8	74.8	74.7
July	77.6	80.6	79.4	79.2
Aug.	76.5	80.2	78.5	78.4
Sep.	70.6	73.3	71.1	71.5
Oct.	50.5	61.5	63.4	59.6
Nov.	47.5	49.0	46.2	47.2
Dec.	36.8	39.4	34.4	36.2
Annual	57.0	59.6	56.6	57.4

about 45 inches in the Ozark uplift section along the lower reaches of the basin. Extreme deviations from this average are 55.13 inches in 1927 and 28.45 inches in 1936." Approximately 65% of the precipitation occurs during the months April to September. Annual snowfall over the basin averages about 12 inches. Average monthly distribution of the rainfall over different sections of the watershed is shown in Table 4.

(2) Climate

The climate of the Grand (Neosho) River Basin is temperate and continental, being characterized by moderate winters and long, relatively warm, summers. Mean annual basin temperature is 57.40°F., with 76.4° and 35.9° as mean summer and winter temperatures respectively. Summer temperatures in the 100°F. range are common, with winter minimums seldom below 5°F. Table 5 gives the average monthly temperature data for various sections of the watershed.

Relative humidity, as compiled by the U. S. Engineer Office, Tulsa, Oklahoma, from monthly data for four U. S. Weather Bureau Stations adjacent to the Grand (Neosho) River watershed is shown in Table 6.

(3) Evaporation

Average monthly evaporation rates, computed by the U. S. Engineer Office, Tulsa, Oklahoma, as representing conditions for the reservoirs in the Grand (Neosho) River watershed are shown in Table 7.

(4) Stream Flow

Stream flows in the Grand (Neosho) River are rather erratic. Flashy flood flows are common and long periods of very low flow with periods of zero flow have been recorded at Iola (mile 292) and Parsons (mile 210) in Kansas. Table 8 shows the maximum, minimum and average annual runoff at six stream gaging stations in various parts of the basin. These figures show an increase in runoff proceeding downstream as the stream traverses continuously more humid areas. The spring-fed Elk and Spring Rivers contribute a disproportionate amount of the base flow of the lower Grand (Neosho) River. Additional stream flow data are shown in Section II, (Problem C), and Appendix A.

Table 6 Data on Relative Humidity in Percent, for various sections of the Grand (Neosho) River Watershed.

Month	KANSAS				MISSOURI		ARKANSAS	
	Wichita		Topeka*		Springfield		Fort Smith	
	Ave. Reading		Ave. Reading		Ave. Reading		Ave. Reading	
	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.	A.M.	P.M.
January	80.6	66.0	75.0	64.4	82.2	70.0	79.9	64.0
February	76.8	56.3	73.6	60.6	80.7	65.4	78.1	60.0
March	73.5	50.2	77.6	58.0	76.5	56.5	74.4	53.6
April	73.6	50.2	77.0	49.3	73.8	53.7	75.6	53.5
May	78.3	50.7	80.0	55.0	78.8	59.3	79.0	58.4
June	77.8	52.1	81.3	52.0	76.8	56.6	80.6	57.3
July	74.5	44.5	74.1	41.0	74.9	50.2	79.1	53.9
August	74.7	45.6	78.0	47.0	75.5	51.4	80.0	54.1
September	78.6	52.4	76.0	43.5	80.8	58.3	82.1	58.0
October	75.7	54.1	71.3	48.0	77.9	57.9	82.3	58.0
November	76.0	58.8	68.6	51.6	77.7	60.8	78.7	59.2
December	80.6	66.1	77.7	66.0	82.0	69.3	79.8	65.2

* Three years of record.

Table 7 Estimated Monthly Evaporation in Inches for Reservoir Sites in the Grand (Neosho) River Watershed.

Month	Marion Reservoir	Council Grove Reservoir	Iola Reservoir	Neel & Waco Reservoirs
January	2.0	1.8	1.8	1.7
February	2.3	2.2	2.0	2.4
March	4.4	4.5	4.2	4.5
April	5.7	5.5	5.2	5.2
May	7.1	6.9	6.6	6.6
June	8.8	8.5	8.1	7.7
July	9.8	9.6	9.8	9.6
August	9.8	9.2	9.1	8.9
September	7.1	6.9	6.9	6.5
October	5.0	4.8	4.7	4.7
November	3.3	3.4	3.1	2.8
December	1.7	1.7	1.5	1.4
Total	67.0	65.0	63.0	62.0

Table 8 Annual Runoff Data for the Grand (Neosho) River and Principal Tributaries for Indicated Period of Record from 1917 to date.

Stream and Station	River Mile	Period of Record	Drainage Area Sq. Mi.	Annual Runoff (Inches) Max.	Min.	Mean
Cottonwood River						
Elmdale, Kans.	453	1922-'32	1,030	11.05	1.07	4.69
Cottonwood F., Kans.	439	1932-date	1,444	4.45	.30	1.80
Grand (Neosho) River						
Iola, Kans.	287	1917-date	3,795	13.1	.72	4.14
Parsons, Kans.	204	1921-date	4,870	16.5	1.06	5.61
Grove, Okla.	105	1925-'39	10,045	21.3	2.37	8.49
Spring River						
Waco, Mo.	175	1924-date	1,160	31.6	1.94	10.00

(C) Economic Background

Agriculture is the principal pursuit in the basin. Mineral resources are quite prevalent; oil, gas, coal, lead, zinc, rock asphalt, rock wool and chat are produced. Manufacturing is confined to agricultural, mining, and domestic supplies. The principal industrial establishments are grain elevators, creameries, cheese plants, flour and feed mills, smelters, white lead and paint works and cement plants. The Rand-McNally Commercial Atlas and Marketing Guide gives the following values for products in the basin above the Grand River Dam (mile 77.7) for the year 1935:

Crops	-	$ 29,880,000
Dairy Products	-	8,829,000
Livestock	-	36,054,000
Manufactured Products	-	35,808,000

Wheat, corn, allied cereals and forage are the principal crops grown in Kansas. Similar crops, with the addition of cotton, are produced in Oklahoma. Numerous vineyards and orchards are located in the Ozark section and berry growing is gaining some prominence in this region.

Oil and gas production is of considerable importance although the fields in the general vicinity of Iola (mile 288) and Chanute (mile 262) are now nearing depletion. The Tri-State area, Kansas, Oklahoma and Missouri, is the scene of the world's greatest zinc and lead production. These lead and zinc mines are experiencing a revival of business after a long period of depression. (Detailed under Problem V, Section Two.) Strip and shaft mining operations in Cherokee and Crawford counties in the southeastern corner of Kansas produce about 2,000,000 tons of bituminous coal annually.

(D) Water, Sewerage, and Industrial Waste

(1) Public Water Supplies

About 255,000 people in 83 municipalities in the Grand (Neosho) Basin are served by public water supply systems. Water from surface sources is used by 107,000 people in 26 communities while 148,000 people in 57 communities use water from underground sources. (See Figure 1,

and Tables 9 and 10.) Sources of satisfactory underground water are not available in much of the Kansas portion of the basin.

The main stem of the Grand (Neosho) River in Kansas is the source of water supply for 14 municipalities and almost 60,000 people. The extremely low flows to which this portion of the river is subject have caused numerous water shortages, especially at Emporia and Council Grove which take water from the Neosho above the mouth of the Cottonwood River. Emporia has constructed three channel dams in the Neosho River and Council Grove has constructed two which are designed to hold several months' supply. Evaporation losses from these shallow reservoirs are quite high. Emporia has constructed a 6,600 acre-foot reservoir on Kahola Creek from which water is released during periods of low flow to keep water behind the channel dams. Council Grove is considering the construction of a similar reservoir.

Below the mouth of the Cottonwood River water shortages have been, in general, less acute. Channel dams of practicable height will store sufficient water to satisfy water needs during the worst droughts. However, several communities along this section of the river have experienced shortages, notably Parsons and Oswego.

(2) Public Sewerage Systems

Public sewerage facilities are available in 54 communities in the Grand (Neosho) Basin. These systems serve about 171,000 persons, of which about 75,000 are on the Neosho Basin above the Kansas-Oklahoma state line. (See Figure 1, and Tables 9 and 10.) Of special significance in this survey is the pollution from about 48,000 people whose wastes are discharged directly to the Cottonwood and Neosho Rivers in Kansas.

Sewage treatment is provided by 43 municipalities in the basin, of which 30 include secondary treatment units. The total sewered organic loading in the basin, including industrial wastes, is computed to be equivalent to the wastes from 204,000 people.

(3) Pollution Due to Industrial Waste

Organic pollution from industries in the Grand (Neosho) River Basin is relatively small, totaling about 30,000 population equivalent, of which about 50% is to Spring River from the Missouri portion of the basin. Industrial organic wastes are principally from creameries, cheese plants, breweries, packing plants, and local abattoirs. Pollution of streams by chemical wastes is of significance due to oil field brine discharges and acid

wastes from bituminous coal mining and lead and zinc production.

Figure 1 shows the general location of the oil fields and Table 18 indicates the number and location of producing oil wells above the Oklahoma-Kansas state line. In this area about 8,000 active wells produce 71,000 bbls. of brine per day with a weighted average chloride content of 33,400 ppm. Of the total brine 19,400 bbls. are reinjected to subsurface formations and 52,000 bbls. are discharged to surface ponds. These impoundments are emptied into tributary streams during periods of high flow.

The bituminous coal mining operations in the Pittsburg area produce large quantities of acid mine drainage. Approximately 90 deep mines and 43 strip mines are active in this region. The number of abandoned mines is considerably larger, but no data are available for estimating their extent. Seven coal-washing plants contribute various quantities of waste coal, iron and acid to the streams. The streams known to be acid are the Blackberry, Lightning, Cherry and Cow Creek. The pollution problem due to the Tri-State Mining operations is discussed in detail in Section II (Problem V).

Figure 2 shows graphically the location of sources of pollution on the Grand (Neosho) River and tributaries,

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FIG. 2

GRAND (NEOSHO) RIVER SEWAGE LOADINGS

U. S. PUBLIC HEALTH SERVICE 1940

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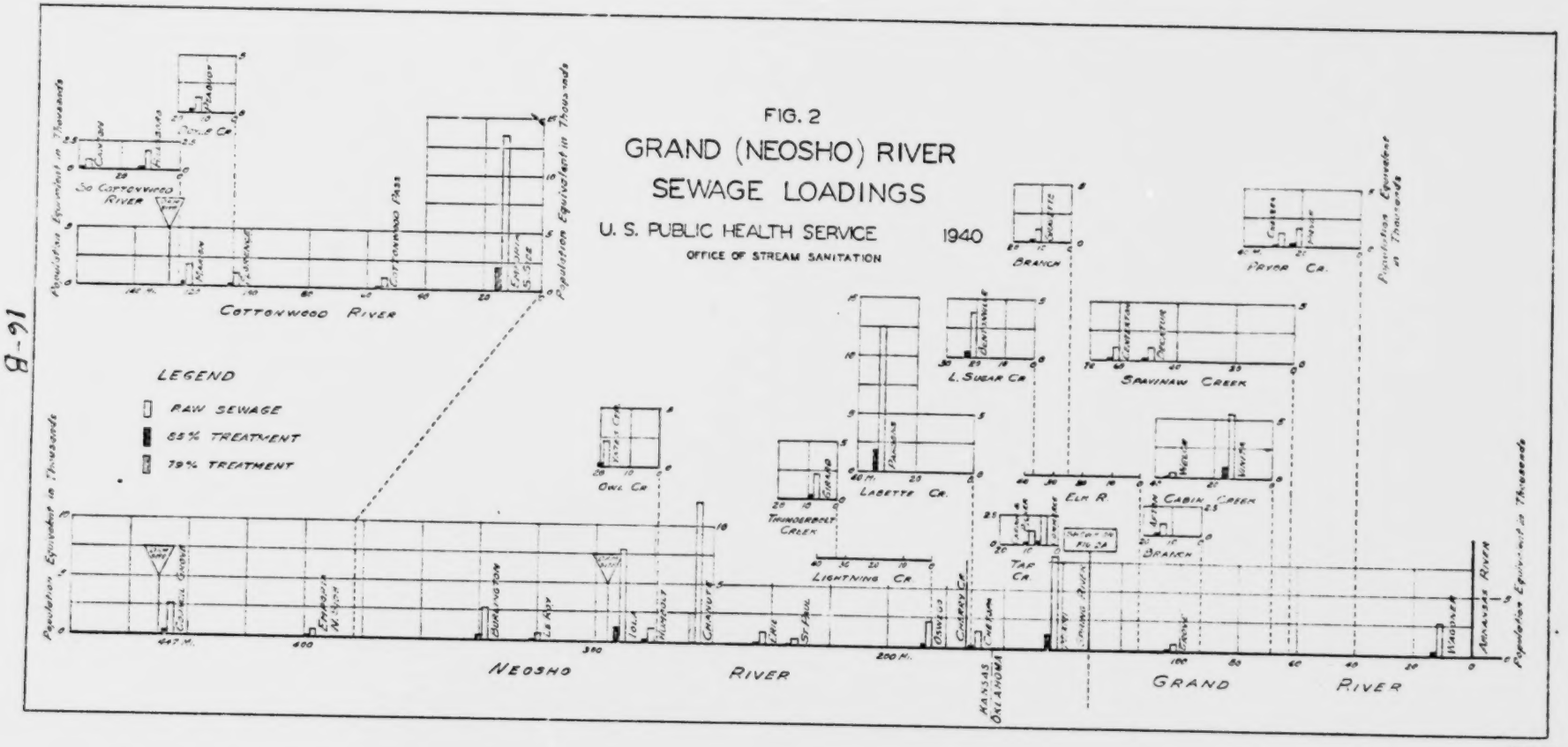

16-B

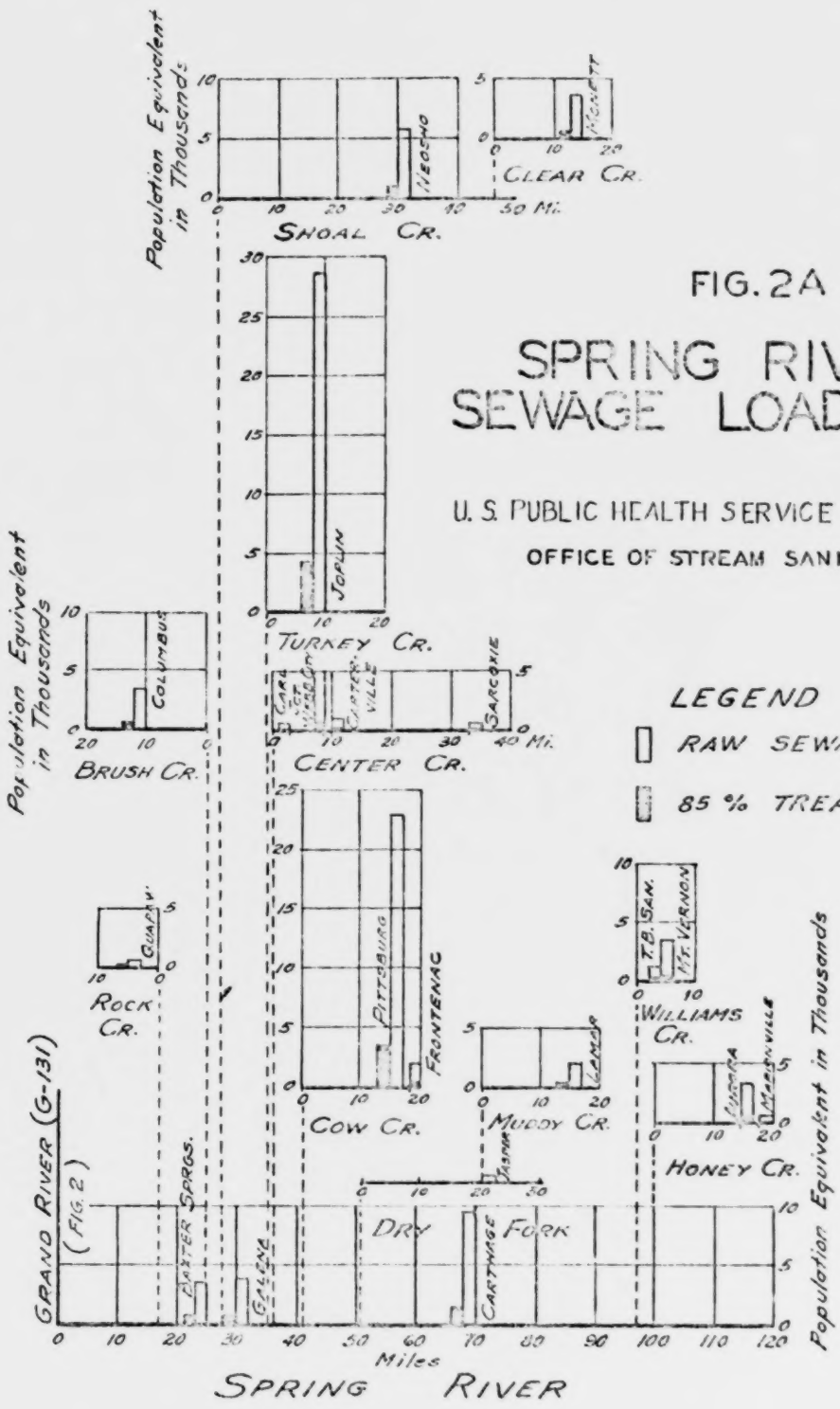

FIG. 2A

SPRING RIVER SEWAGE LOADINGS

U. S. PUBLIC HEALTH SERVICE 1940

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16-C

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Table 9 Tabulation, by Streams and Municipalities, of Salient Water Supply, Sewerage and Sewage Treatment Features.

Municipality	State	River Mileage	Public Water Supply: Source Supply	Consumption M.G.D.	Treatment (3)	Sewerage and Sewage Treatment: Pop. Equiv. Served by Sewerage System	Sewage Flow M.G.D.	Treatment (4)	Gross Pop. Equiv. (1)
Grand River									
Ft. Gibson	Okla.	G-2	Grand R.	.050	E.D	-	-	-	-
Muskogee (5)	"	G-2	Grand R.	4.000	F.D.	-(5)	-(5)	-(5)	-(5)
Wagoner	"	G-12	Grand R.	.150	F.D.	2800	.100	T	2800
Pryor Creek		G-40							
Pryor	"	P-22	Grand R.	.075	F.D.	1700	.065	S	1700
Chelsea	"	P-28	Pryor Cr.	.030	F.D.	1200	.025	T	1200
Spavinaw Creek		G-62							
Decatur	Ark.	Spa-52	-	-	-	-	-	-	1100 (2)
Centerton	"	Spa-62	-	-	-	-	-	-	1100 (2)
Cabin Creek		G-69							
Vinita	Okla.	CC-15	Grand R.	.250	F.D.	5500	.200	S	5500
Welch	"	CC-35	Well	.018	0	350	.015	S	350
Branch		G-93							
Afton	Okla.	Br-14	Well	.060	A.D.	1000	.040	T	1000
Grand River									
Grove	Okla.	G-103	Grand R.	.030	F.D.	600	.025	0	600
Elk River		G-114							
Branch		El-25							
Gravette	Ark.	Br-12	-	-	-	-	-	-	1100 (2)
L.Sugar Creek		El-37							
Bentonville	Ark.	LSu-23	Well	.076	0	3800	.090	S	3800
Spring River		G-131							
Rock Creek		Sp-17							
Quapaw	Okla.	Ro-5	Wells	.025	0	500	.020	P	500
Spring River		G-131							
Baxter Spgs.	Kans.	Sp-23	Well		A.F.	3600		0	3600
Brush Creek		Sp-25							
Columbus	Kans.	Br-12	Well		A	3300	.015	S	3300

Table 9 (Continued)

Municipality	State	River Mileage	Public Water Supply: Source Supply	Consumption M.G.D.	Treatment (3)	Sewerage and Sewage Treatment: Pop. Equiv. Served by Sewerage System	Sewage Flow M.G.D.	Treatment (4)	Gross Pop. Equiv. (1)
Shoal Creek		Sp-27							
Neosho	Mo.	Sh-30	Well	.350	D	5800	.200	P	5800
Clear Creek		Sh-46							
Monett	Mo.	Cl-13	Wells	.350	D	3600	.175	S.D.	3600
Spring River									
Galena	Kans.	Sp-30	Well		0	3800		0	3800
Turkey Creek		Sp-35							
Joplin	Mo.	Tu-8	Shoal Cr.	3.250	F.D.	28600	2.500	T	28600
Center Creek		Sp-36							
Carl Jct.	Mo.	Ce-3	Wells	.075	0	600	.030	0	600
Webb City	"	Ctr-9	Wells	.215	D	5000	0.300	0	5000
Carterville	"	Ce-10	Webb City			1000	.050	0	1000
Sarcoxie	"	Ce-33	Well	.025	0	500	.025	P	500
Cow Creek		Sp-41							
Pittsburg	Kan.	Ce-17	Well	1.800	L.F.	16100	1.600	S	22900
Frontenac	"	Ce-18	Well	.190	A	1900	.060	S	1900
Dry Fork		Sp-51							
Jasper	Mo.	Dr-20	Well	.025	0	200	.010	T	500
Muddy Creek		Dr-20							
Lamar	Mo.	Mu-15	Muddy Cr.	.200	F.D.	2000	.168	S	2000
Spring River									
Carthage	Mo.	Sp-68	Wells	.600	F.D.	9500	.350	S	9500
Williams Creek		Sp-97							
T.B. San.	Mo.	Wi-4	Wells		0	1200	.120	T	1200
Mt. Vernon	"	Wi-4	Wells	.225	0	1500	.075	P	3500
Honey Creek		Sp-100							
Aurora	Mo.	Ho-14	Springs	.250	E.D.	3200	.150	S	3200
Marionville	"	Ho-17	Well	.050	0	-	-	-	400 (2)

Table 9 (Continued)

Municipality	State	River Mileage	Public Water Supply: Source Supply	Consumption M.G.D.	Treatment (3)	Sewerage and Sewage Treatment: Pop. Equiv. Served by Sewerage System	Sewage Flow M.G.D.	Treatment (4)	Gross Pop. Equiv. (1)
Neosho River									
Tar Creek		N-142							
Commerce	Okla.	Ta-6	Wells	.200	0	2500	.100	S	2500
Cardin	"	Ta-10	Wells	.010	0	15	Picher		
Picher	"	Ta-10	Wells	.060	0	1200	.025	0	1200
Neosho River									
Miami	Okla.	N-144	Wells	.650	0	8000	.350	S	8000
Chetopa	Kan.	N-170	Neosho	.065	F.L.	1400		0	1400
Labette Creek		N-171							
Parsons	Kan.	La-33	Neosho	2.000	F.L.	12500	1.00	S	12500
Lightning Creek		N-185							
Thunderbolt Cr.		Li-33							
Girard	Kan.	Th-8	Well	-	A	2200	.110	S	2200
Neosho River									
Oswego	Kan.	N-187	Neosho	.200	F.L.	2200	.400	S	2200
St. Paul	"	N-233	Neosho	.020	F.L.	500	.040	S	500
Erie	"	N-244	Neosho	.200	F.L.	1000	.060	T	1000 (3)
Chanute	"	N-266	Neosho	1.0	F.D.	10900	.662	T	12200
Owl Creek		N-279							
Yates Cr.	Kan.	Ow-19	Impounded	.215	F.D.	2200		S	2200
Neosho River									
Humboldt	Kan.	N-280	Neosho	.300	F.D.	1200	.100	S	1200
Iola	"	N-292	Neosho	.770	F.D.	7500	.535	S	8100
Gas City	"	N-292	Neosho	From Iola		-	-	-	-
LaHarpe	"	N-292	Neosho	" "		-	-	-	-
LeRoy	"	N-321	Neosho	.030	F.D.	500	.050	S	500
Burlington	"	N-339	Neosho	.350	F.D.	2700	.270	S	2700
Cottonwood River		N-383							
Emporia (S. Sd.)	Kans.	Co-14	Neosho	2.100	F.D.	13400	.649	S	13400
Cottonwood F.	"	Co-56	Well	.055	A	1000	.070	S	1000
Florence	"	Co-106	Spring	.041	0	1300	.090	T	1300

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Table 9 (Continued)

Municipality	State	River Mile-age	Public Water Supply: Source Supply	Consumption M.G.D.	Treatment (3)	Sewerage and Sewage Treatment: Pop. Equiv. Served by Sewerage System	Sewage Flow M.G.D.	Treatment (4)	Gross Pop. Equiv. (1)
Doyle Creek		Co-106							
Peabody	Kans.	Do-14	Well	.055	O	1300	.030	T	1300
Cottonwood River									
Marion	Kans.	Co-122	Mud Cr.	.570	F.D.	1800	.144	S	1800
So. Cottonwood R.		Co-125							
Hillsboro	Kans.	Sco-12	Well	-	O	1700	.085	S	1700
Canton	"	Sco-32	Well	-	O	800	.040	S	800
Neosho River									
Emporia (N. Sd.)	Kans.	N-398	Above			600	.040	S	600
Council Grove									

NOTES:

(1) Includes Industrial Wastes not connected to municipal system.

(2) Industrial Wastes only.

(3) Water Treatment Symbols.
- A - Aeration
- D - Disinfection
- E - Settling
- F - Coagulated, settled and filtered (Including aeration, activated carbon and recarbonation in some plants.)
- L - Softening
- O - No treatment

(4) Sewage Treatment Symbols.
- T - Septic tank
- P - Primary treatment
- S - Secondary treatment
- D - Disinfection
- O - No treatment

(5) Not in Grand River Basin. Water supply from Grand River.

Table 10 Summary, by Stream Sections, of Salient Water Supply, Sewerage, and Sewage Treatment Data for the Grand (Neosho) River Watershed.

	Grand R. Mouth to Spring R. (Exclusive of Elk R.)	Elk River	Spring River	Neosho R. Spring R. to Iola Dam Site	Neosho R. Iola Dam Site to Cotton-wood R.	Cotton-wood River	Neosho R. above Cotton-wood River	Total
	0 - 131	114	131	131-296	296-383	383	383-478	
Sewerage								
Communities Served	9	2	19	14	2	7	1	54
Sewered Population	12,250	1,800	83,000	48,950	2,900	19,200	2,800	170,900
Treatment Plants								
Primary	3	0	6	2	0	2	0	13
Secondary	3	1	7	10	2	5	2	30
Population Equivalent* (Untreated Waste)	15,350	4,900	100,900	55,250	3,200	21,400	3,300	204,300
Water Supply								
Communities Served	12	5	30	21	4	8	3	83
Source of supply								
Ground Water	5	5	28	10	1	7	1	57
Surface Water	7	0	2	11	3	1	2	26
Population Served								
Ground Water	2,760	3,595	74,425	18,555	300	7,100	325	107,060
Surface Water	46,800	0	35,150	44,650	3,250	1,800	16,500	148,150

* Including industrial wastes not connected to sewerage systems.

together with population equivalent loadings of untreated and treated wastes.

(E) Water Development Plan

(1) Existing Reservoirs

The Grand River Dam Authority, an agency of the State of Oklahoma, is constructing a hydroelectric project on the Grand (Neosho) River at mile 77.7. This project will create the largest reservoir in the basin, with a capacity of 1,680,000 acre-feet. The initial power development at this dam will be 64,000 KW. Further power projects are proposed at Markham Ferry and Fort Gibson. These would utilize the entire fall of the lower section of the river.

A reservoir of 7,500 acre-feet capacity has been created by a dam 30 feet high on the Spring River at Lowell, Kansas. The 3,000 KW hydroelectric plant at the dam is operated during low flow periods to carry daily peak loads in an interconnected system using steam power to carry base load. This operation causes large diurnal fluctuations in the stages of Spring River below the plant. There are a number of other smaller power dams in the basin as well as low channel dams at municipal water supply intakes. None of these exceed 1,000 acre-feet in capacity.

Recreational lakes, water supply impounding reservoirs and stock ponds complete the existing reservoir development. Lake Spavinaw, on Spavinaw Creek (mile 61), the largest of these, has a capacity of approximately 30,000 acre-feet and furnishes the water supply for Tulsa, Oklahoma. Lake Kahola, on Kahola Creek (mile 423), with a capacity of about 6,600 acre-feet, is used to supplement the natural flow of the Grand (Neosho) River for the water supply of Emporia, Kansas. It is the only other large water supply reservoir in the basin.

(2) Proposed Reservoirs

Reservoirs on the Neosho River above Iola (at mile 296) and above Council Grove (at mile 450) and on the Cottonwood River above Marion (at mile 510) have been studied by the U. S. Engineer Department. Table 11 shows salient features of these three reservoirs.

Table 11 Salient Features of Council Grove, Marion and Iola Reservoirs.

Feature	Council Grove	Marion	Iola
Stream	Grand (Neosho)	Cottonwood	Grand (Neosho)
River Mile	450	510	296
Drainage Area (sq. mi.)	250	206	3,580
Storage:			
Total (acre-feet)	100,000	90,000	322,000
Conservation (acre-ft.)*	50,000	30,000	22,000
Flood (acre-feet)	50,000	60,000	300,000
Area Inundated:			
Maximum pool (acres)	5,650	6,970	27,700
Conservation pool (acres)	3,300	3,370	3,450
Flood pool (acres)	4,900	6,370	24,000

*Includes siltation reserve.

(F) Public Health Significance

Based on available epidemiological data, there appears to be no definite correlation between present stream conditions and the incidence of water-borne diseases.

Typhoid fever in the Kansas portion of the basin averages about 30 scattered cases per year. Reported cases of dysentery totaled 38 for the past seven years. In Kansas no typhoid epidemics have been traced to municipal water supplies since 1917.

Gastro-enteritis is not a reportable disease and no epidemiological statistics are available to indicate its incidence in the basin. According to the Kansas state epidemiologist no consequential outbreaks in the Kansas

portion of the basin have been noted. However, spasmodic intestinal disturbances are known to occur.

Records of the Kansas State Health Department indicate that 27 cases of malaria were reported from the Grand (Neosho) Basin during the 7-year period, 1933-39. In July-August 1938 a preliminary mosquito survey covering 61 Kansas counties was made by the U. S. Public Health Service in collaboration with the Kansas State Board of Health. This investigation included 16 of the 19 counties of the Grand (Neosho) Basin in Kansas and indicated the presence of the Anopheles quadrimaculatus in 11 counties. However, according to the Kansas State Board of Health, the construction of the proposed reservoir system has not been considered significant in the malaria control problem.

SECTION TWO

Specific Problems Propounded by U. S. Engineer Department

The investigation of the Grand (Neosho) River Basin, as reported herein, was primarily to analyze the following five specific problems propounded by the U. S. Engineer Department as relating to the proposed water development plan of the basin:

(I) Determine what possible alternate sources of public water supply are available to towns now dependent on the Neosho River, with special attention to the possibility of developing satisfactory supplies from underground sources.

(II) Determine the relative merits of the proposed reservoirs on the Cottonwood and Neosho Rivers as sources of public water supply from a standpoint of chemical, bacterial and biological quality.

(III) Considering the maximum conservation storage in the Council Grove and Marion reservoirs at 47,000 and 27,500 acre-feet respectively, determine the adequacy of these storage capacities for pollution abatement and water supply use and the desirable rates of release for these purposes.

(IV) Determine the estimated monetary value of water stored in these reservoirs for pollution abatement and municipal water supply purposes.

(V) Determine the significance of stream pollution in the Spring and Elk (Cow Skin) River basins, practical control measures, and the value of conservation storage in the Waco and Neal reservoirs for pollution correction.

Time limitations dictated the approach to the problems based on collection and analysis of existing data from various governmental agencies, especially the U. S. Engineer Department and the State Health Departments of Kansas, Missouri, Oklahoma and Arkansas, supplemented by limited field investigations and laboratory determinations.

Data relating to physiographic, hydrometric, climatic and economic conditions in the basin, together with general water supply and pollution problems are presented, in summary discussions and tabulations, in Section One. Supplemental data, where applicable, are in the following detailed discussions of the specific problems.

Problem (I) Determine what possible alternate sources of public water supply are available to towns now dependent on the Neosho River, with special attention to the possibility of developing satisfactory supplies from underground sources.

(A) Summary of Conclusions

(1) Experience of municipalities in attempting to develop satisfactory underground water supplies along the Grand (Neosho) River in Kansas definitely indicates such developments to be impractical.

(2) Underground water is limited in quantity, is highly mineralized, and is not economical to develop, except possibly for small communities with demands below 30,000 gallons per day.

(3) Surface streams provide the only adequate, satisfactory source of municipal water supply along the Grand (Neosho) River in Kansas.

(4) An adequate and satisfactory source of water supply for Kansas communities now using the Grand (Neosho) River can be insured by low flow augmentation from upstream reservoirs, by channel impoundments near the supply intake, or in some instances, by constructing impounding reservoirs on tributary streams.

(B) Discussion of the Problem

(1) Sources of Water Supply

In Kansas 14 municipalities, with a total population of about 60,000, use the Grand (Neosho) River as a source of water supply. One town in this area, Hartford (population 516), uses underground water but the supply is limited in quantity and is of poor chemical quality.

The aquifers which furnish the water supplies of the municipalities in the Spring and Elk Basins dip to the west and north. In the Grand (Neosho) Valley these are quite deep and their water is too highly mineralized for satisfactory domestic or industrial use. Shallow rock formations do not furnish appreciable amounts of water. The alluvial fill furnishes the water supply of most of the farm wells and is the source of the Hartford supply.

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Numerous communities in the valley above Parsons (mile 204) have attempted in the past to develop water supplies from underground sources. At Emporia, Kansas, a number of wells were drilled and tested. With continuous pumpage the drawdown increased as did the upward trend of hardness and iron content. Similar conditions were found at other municipalities.

In the southeast portion of the Grand (Neosho) Basin in Kansas, several communities obtain water supplies from the same aquifers used by municipalities in the Spring River Basin. Chetopa, Kansas (mile 170), now using water from the Grand (Neosho) River, formerly had a well supply of reasonably adequate quantity, but high floride content necessitated its abandonment.

Although no comprehensive study has been made of the underground water resources of the Grand (Neosho) Valley, all experiences indicate that reliable underground water supplies cannot be developed economically, excluding possibly where the water demand is below 30,000 g.p.d. However, in all cases the chemical quality of the water would not be comparable to surface sources.

(2) Geological Background

In the southeastern corner of Kansas, including Cherokee County and portions of adjoining Labette and Crawford counties, (mile 165 to 190), water is obtainable principally from the Mississippian limestone, 400 to 500 feet thick, underlying the Cherokee shale. This water, derived from rainfall entering the formation at outcrops in Missouri, is of fair chemical quality and is used as the municipal supply for several cities such as Columbus (mile 190) and Pittsburg (Spring River Basin).

In several counties in the Neosho area (mile 210 to 270), where the underlying rocks consist primarily of shale and escarpment-making limestone, there are few, if any, formations that bear appreciable quantities of water, although supplies adequate for farm wells are found through the region.

In the area around Emporia, Kansas (mile 390) the most important geologic elements consist of escarpment-making limestone formations, separated by relatively impervious clay and calcareous shale. There is little sandstone. Ground water supplies are frequently insufficient for ordinary farm and stock use and are far too limited for municipal use.

In the Cottonwood Basin is found the outcrop area of Permian shales, belonging mostly to the Wellington formation. The area is characterized by limited quantity and poor quality underground water obtained from surficial materials and the weathered outcrop of more porous strata in the shaly rock. Underground water is generally highly mineralized due to abundance of gypsum and salt in the underlying bed rock.

From analysis of information it is concluded that underground water as a source of municipal supply in the Grand (Neosho) River Basin in Kansas is not dependable with the exception of the extreme southeast corner of the state. Beyond this small section there are occasional small narrow beds of good water-bearing sandstone, but these are difficult to locate and do not provide large supplies of water. The remainder of the basin is not geologically suited to ground water storage or movement and does not yield water in large or dependable quantities.

Problem (II) Determine the relative merits of the proposed reservoirs as potential sources of public water supply from the standpoint of chemical, bacterial and biological quality.

(A) Summary of Conclusions

(1) Available chemical determinations show that the Grand (Neosho) River at Council Grove is more suitable as a source of domestic and industrial water supply than the Cottonwood River at Marion.

(2) All data indicate that water impounded at Council Grove and Marion will be of good bacterial quality. Satisfactory oxygen relations appear assured in both impoundments.

(3) Bacterial concentrations in the Iola reservoir may be somewhat higher than those in the two upstream reservoirs. The chemical quality of the Grand (Neosho) River at Iola is not as good as at Council Grove but is decidedly better than the Cottonwood River at Marion. The quality of the discharges, however, will doubtless show improvement over the present uncontrolled stream flows. Oxygen relations in the Iola Reservoir should be satisfactory.

(4) From the standpoint of bacterial quality, water in all three reservoirs will be suitable for public water supplies following treatment. Chemical data indicate that the water impounded at Council Grove falls in the weighted average total hardness range of 150 to 250 ppm., with about 85% as carbonate hardness. At Marion average total hardness will be higher with about 50% as carbonate hardness.

(5) Higher mineralization and lower average depths in the Marion Reservoir are conducive to greater biological development than at the Council Grove Reservoir. The diminution in plankton count after several days flow in the river would tend to reduce the effect of reservoir storage on taste and odor problems at Emporia and Iola.

(B) Discussion of Problem

(1) Chemical Quality

Chemical examinations of raw river water at Council Grove are made annually by the Kansas State Board of Health. Because no municipality uses Cottonwood River water, few data are available as to its chemical quality.

The Cottonwood drains a considerable area where gypsiferous rocks are exposed and also drains a number of oil fields. Consequently, the stream waters have a relatively high sulfate content and non-carbonate hardness from the natural rock formations, and a relatively high chloride content from the oil field brines. As a result of poor chemical quality of Cottonwood River water, Emporia has constructed an impounding reservoir on Kahola Creek rather than use the Cottonwood River to supplement its Grand (Neosho) River supply.

Samples of Cottonwood River water at the Marion Dam site were collected and examined during the period June 7-12, 1940.

Average results (Cottonwood River at Marion) are as follows:

Determination	Results (ppm)
Hardness - Total	335
Hardness - Carbonate	167
Hardness - Non-carbonate	168
Chlorides	45

The average results of seven annual raw water chemical examinations at Council Grove (Grand (Neosho) River) are:

Determination	Results (ppm)
Hardness - Total	246
Hardness - Carbonate	206
Hardness - Non-carbonate	40
Chlorides -	7

These figures show that the water at Council Grove is much softer than that at Marion and that the non-carbonate or permanent hardness is less than one-fourth as high. The chloride content is lower but at neither reservoir would the chloride content be high enough to give the water a noticeable taste. There is only one small oil field above the proposed Marion Dam and the larger oil and gas fields in the Cottonwood Basin are located below this site.

Since both the Cottonwood and the Neosho Rivers are very flashy streams in the vicinity of the Marion and Council Grove dam sites, it is not feasible to make accurate predictions as to the chemical quality of the reservoir water without data on daily variations in flow and in chemical quality over a considerable period of time. Such data are not available.

In general, the hardness of the river water is higher at low flows than at high flows. The reservoirs

will tend to improve the average quality of the water over that which prevails under present uncontrolled conditions by retaining much of the soft water which now is available only during high flows.

During the period when the samples were taken from the Cottonwood River, the flow of the stream at Cottonwood Falls averaged about 280 c.f.s. This is greater than the mean flow at the station so the samples doubtless represent conditions somewhat better than will actually occur in the reservoir. The average results shown for Council Grove may be worse than will prevail in the reservoir since a number of the samples were taken during low flow periods.

(2) Bacterial Quality

The number of coliform organisms in both the Marion and Council Grove reservoirs will be low. There is a very limited discharge of contaminated material into the streams on the reservoirs' catchment area. Further, storage time, sedimentation and effect of sunlight will result in a rapid diminution in bacterial life in the reservoirs.

The bacterial quality of the water in the Iola Reservoir will be better than under present conditions.

Effects of storage and dilution from upstream reservoirs will be beneficial.

(3) Biological Quality

The extreme paucity of data relating to the biological quality of existing reservoirs in the area limits prediction of impounded water quality with regard to plankton development and the attendant taste and odor troubles. Experience, in general, indicates that plankton flourish and are exceedingly numerous during the first few years of reservoir operation. As biological stability in the impounded water approaches, there is a marked reduction in total number of organisms. High mineralization generally increases plankton growth and relatively shallow flowage areas also tend to encourage biological development.

Limited biological investigations of reservoirs discharging to streams indicate a general diminution of organisms during several days' stream flow. This behavior does not follow any known mathematical law but will be influenced by physical stream conditions, types of lake plankton and food relations and availability. These phenomena would tend to reduce taste or odor problems at and below Emporia.

Taste and odor problems at and immediately below Iola Reservoir may be significant. Plankton development in this reservoir very likely will be abundant.

Problem (III) Considering the maximum conservation storage in the Council Grove and Marion reservoirs at 47,000 and 27,500 acre-feet respectively, determine the adequacy of these storage capacities for pollution abatement and water supply use and the desirable rates of release for these purposes.

(A) Summary of Conclusions

(1) In the Grand (Neosho) River organic pollution abatement by stream regulation from conservation storage should be combined with reasonable treatment of organic waste prior to discharge. It is infeasible to provide minimum stream flows sufficient properly to dilute oil field wastes in the quantities produced.

(2) Stream flow regulation from conservation storage as indicated would have theoretically provided, during the worst drought of record, necessary minimum flows to dilute treated organic wastes (85% 5-day B.O.D. reduction), prevent water shortages and improve general stream conditions.

(3) Desirable seasonal releases, utilizing the maximum conservation storage of 47,000 and 27,500 acre-feet in Council Grove and Marion reservoir respectively, are as follows:

	Marion	Council Grove
December - May	0 c.f.s.	10 c.f.s.
June - September	20 "	30 "
October - November	10 "	30 "

(4) If 10,000 acre-feet conservation storage were provided in the Iola flood control reservoir, a highly desirable minimum regulated flow of 50 c.f.s. could be maintained below Iola. Under this arrangement Council Grove conservation storage could be reduced to 20,000 acre-feet, for maintenance of a constant minimum discharge of 20 c.f.s.

(5) The following tri-reservoir plan of development and operation appears to provide the most equitable solution to low flow problems in the Grand (Neosho) River:

(a) Marion Reservoir on the Cottonwood River, with conservation storage of 27,000 acre-feet, operated primarily for pollution abatement with seasonal releases as indicated under (3).

(b) Council Grove Reservoir on the upper Neosho River, with 20,000 acre-feet conservation storage, operated with a constant discharge of 10 c.f.s. This flow is adequate for water supply and sewage dilution needs above the Cottonwood River confluence.

(c) Allocation of 10,000 acre-feet conservation storage in the proposed Iola flood control reservoir to regulate minimum flow below Iola at 50 c.f.s.

(B) Discussion of Problem

(1) General

At present the Grand (Neosho) and its principal upstream tributary, the Cottonwood, are subject to extended periods of near zero flow. The proposed reservoir system would provide beneficial low flow control above Chetopa, Kansas (mile 170). In this area these streams are used as a source of water supply and a final receptacle for wastes from a sewered population of about 50,000. Figure 3 and Table 12 show data on water supply, waste disposal, and relative locations of the municipalities using the stream.

Below Chetopa the water supply and dilution requirements are satisfied either by the Grand River dam reservoir or the minimum releases from this reservoir. Muskogee, Oklahoma (Arkansas Basin) uses the Grand (Neosho) River as a source of water supply with an intake 1/4 mile above the Arkansas River confluence. Quality of water at this intake has in the past and may in the future be affected by backwater from the Arkansas River, especially if minimum flow in the Grand (Neosho) River is reduced beyond reasonable limits.

Total water consumption from the Grand (Neosho) River in Kansas averages about 11 c.f.s. Emporia, the largest consumer, requires less than 4 c.f.s. Flows in excess of 11 c.f.s. are required to maintain satisfactory oxygen relations. Figure 2 depicts points of pollution on the Grand (Neosho) and its tributaries, together with organic loadings, as population equivalent, for untreated and treated wastes.

(2) Organic Pollution Abatement

Satisfactory disposal of municipal waste is normally accomplished by proper treatment, plus dilution in surface streams. Effective primary and secondary treatment, equivalent to an 85% reduction of the 5-day B.O.D., is practicable and should be provided as a minimum by all sewered communities in the basin.

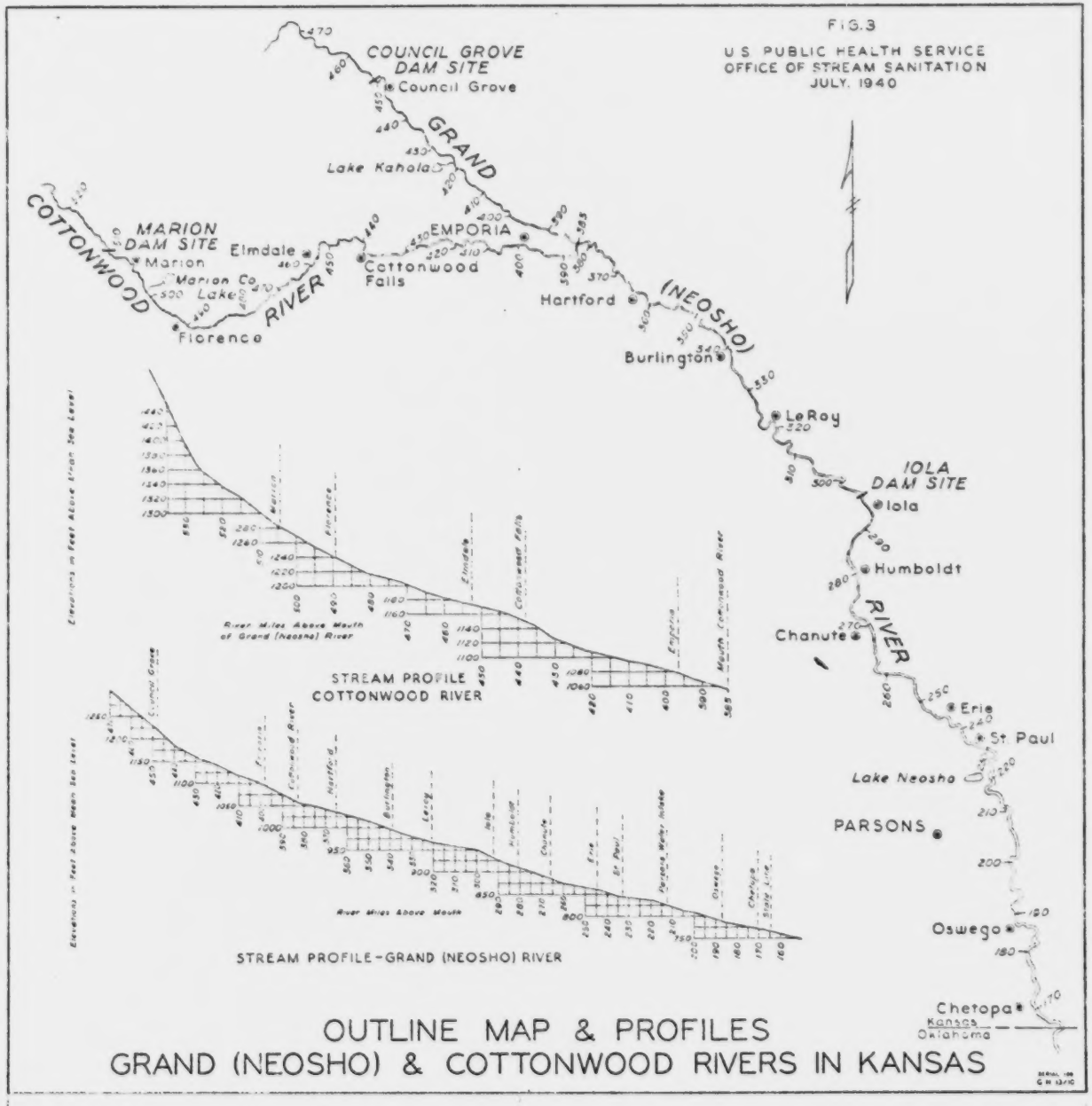


FIG.3
U.S. PUBLIC HEALTH SERVICE
OFFICE OF STREAM SANITATION
JULY, 1940
COUNCIL GROVE DAM SITE
Council Grove
GRAND
Lake Kahola
MARION DAM SITE
Marion
Marion Co. Lake
COTTONWOOD RIVER
Florence
Elmdale
Cottonwood Falls
EMPORIA
Hartford
(NEOSHO)
Burlington
LeRoy
IOLA DAM SITE
Iola
Humboldt
RIVER
Chanute
Erie
St. Paul
Lake Neosho
PARSONS
Oswego
Chetopa
Kansas
Oklahoma
STREAM PROFILE COTTONWOOD RIVER
STREAM PROFILE-GRAND (NEOSHO) RIVER
OUTLINE MAP & PROFILES
GRAND (NEOSHO) & COTTONWOOD RIVERS IN KANSAS

Table 12 Municipalities Tributary to Cottonwood and Grand (Neosho) Rivers Showing Principal Data on Water Supply and Waste Loadings.

Municipality	River Mile	Public Water Supply		Sewage Flow M.G.D.	Population Equivalent as B.O.D.		
		Source	Consumption M.G.D.		Served	Gross	With 85% B.O.D.Red.
Cottonwood River							
Marion, Kansas	Co-122	Mud Creek	.570	.144	1,800	1,800	270
Cottonwood Falls	Co- 56	Well	.055	.070	1,000	1,000	150
Emporia,(So.Sd.)	Co- 14	Neosho R.	2.100	.649	13,400	13,400	2010
Neosho River							
Council Grove	N-447	Neosho R.	.550	.220	2,700	2,700	405
Emporia (N.Sd.)	N-398	See above	--	.040	600	600	90
Burlington	N-339	Neosho R.	.350	.270	2,700	2,700	405
LeRoy	N-321	Neosho R.	.030	.05	500	500	75
Iola	N-292	Neosho R.	.770	.535	7,500	8,100	1215
Humbolt	N-280	Neosho R.	.300	.100	1,200	1,200	180
Chanute	N-266	Neosho R.	1.000	.662	10,900	12,200	2560*
Erie	N-244	Neosho R.	.200	.060	1,000	1,000	150
St. Paul	N-233	Neosho R.	.020	.040	500	500	75
Parsons	N-215	Neosho R.	2.000	2.000**	12,500	12,500	1875
Oswego	N-187	Neosho R.	.200	.400	2,200	2,200	330
Chetopa	N-170	Neosho R.	.065	--	1,400	1,400	210

*Composite Reduction Municipal and Industrial Waste of 79%.
** Sewage discharged to Labette Creek (Mile 33).

The quantity of diluting water required for abatement measures in the Cottonwood River is controlled by the pollution load entering the stream at Emporia. This city, with a sewered population equivalent of 14,000, is served by two systems; the larger, tributary to the Cottonwood River, covers the business and industrial sections and serves 13,400 population, or about 96% of the total load. The other system, tributary to the Grand (Neosho) River, serves a small residential area and handles gross wastes from a population equivalent of 600, or about 4% of the total.

The critical point on the Neosho River is at and below Chanute (mile 266) which discharges sewage having a gross population equivalent of 12,200.

(3) Flow Control

Minimum flow requirements properly to dilute organic waste effluents were computed on the basis of simple dilution (reoxygenation excluded), and also considering reaeration at a very low rate (K_2 = 0.1 in Streeter-Phelps formula*). This approach was used because no laboratory determinations of actual rates of

* H. W. Streeter and E. B. Phelps. "A Study of the Pollution and Natural Purification of the Ohio River. III. Factors Concerned in the Phenomena of Oxidation and Reaeration." Public Health Bull. 146, U.S.Public Health Service (1925)

reoxygenation at critical flows were available.

This analysis considers the following two significant conditions, within the range of which the stream behavior will probably fall:

(a) With organic matter undergoing a rapid rate of deoxygenation and time for negligible stream reoxygenation, the maintenance of a 3 p.p.m. minimum dissolved oxygen residual would require flows of sufficient dissolved oxygen content to satisfy total first stage demand (simple dilution).

(b) With a slow rate of deoxygenation ($K_1 = 0.1$) and use of a conservative value of reoxygenation ($K_2 = 0.1$), in which case required dilutions would be less but with pollution influence extending a maximum time of flow downstream (slow stream recovery).

Should conditions approach the need for flows based on simple dilution, stream recovery would be rapid and the sphere of influence would be restricted with the critical zone of oxygen depression immediately below outfalls. With slow rates of deoxygenation and reoxygenation, the critical zone would extend downstream with a less pronounced but a definitely prolonged oxygen sag.

Physical characteristics of the Grand (Neosho) River, as indicated in Section One, favor rapid stream purification. Under actual conditions, the oxygen deficits, with the corresponding dilutions, would likely be less than the indicated values and the zones of influence restricted.

(a) Cottonwood River - Table 13 shows flow requirements by months for Emporia, together with minimum flows of record for the Cottonwood River near Elmdale and at Cottonwood Falls.

A comparison of these indicates flow deficits for periods of at least 7 days for all months except February and March on a "straight dilution" basis, and for June to October inclusive on the basis of conservative reaeration. While November does not show a deficit under the latter conditions, its slight margin warrants its inclusion in regulated flow considerations.

A study of possible regulated releases from the maximum conservation storage of 27,500 acre-feet at Marion Reservoir indicates that the water available would be insufficient to satisfy extreme conditions approaching "straight dilution". There would be, however, sufficient water available to meet all the requirements under conditions of conservative reaeration. A desirable distribution of releases within practical limits was determined by dividing the most critical period of June to November, inclusive, into summer and fall seasons of four and two months respectively and applying reservoir releases for each season as a unit. A flow distribution of 2 to 1 for the summer and fall seasons was determined by comparison of the relative flow requirements for the most critical

month in the season (July and October respectively- Table 13).

Using stream flow data furnished by the U. S. Engineer Department (see Appendix A) and evaporation rates as shown in Table 7, Section One, computations indicate that releases of 20 c.f.s. during June, July, August and September, and 10 c.f.s. during October and November could have been made during the worst drought of record. These releases would have satisfied all of the flow deficiencies shown under reaeration computations in Table 13. They represent as satisfactory a practical seasonal distribution of the releases as could be determined.

Should required dilutions approach flows such as those indicated under simple dilution, regulated releases may not offset all indicated deficiencies. If this unlikely condition occurs, minimum oxygen residuals could be maintained immediately below the outfall by additional waste treatment, such as chlorination. Such an addition would not affect computed economic benefits in Problem IV.

Table 14 shows the minimum weekly average flows at Emporia with the above mentioned reservoir releases and the resultant theoretical minimum dissolved oxygen content in the stream below Emporia. From the table, the minimum

Table 13 Record Low Flows in Cottonwood River and Theoretical Dilution Flows Required to Maintain 3 p.p.m. Residual Dissolved Oxygen at Critical Point below Emporia.

Month	Stream Temp. °C. (1)	Lowest Flow of Record (5) - C.F.S.			Min. Dilution Flow Required at Emporia - C.F.S. (2)			
					Neglecting Reaeration		With Reaeration(3)	
		Day	Month	7-day period	Required	7-day deficit	Required	7-day deficit
Jan.	5	3(4)	10.0	3(4)	8.3	5.3	1.4	0
Feb.	5	8	11.6	9	8.3	0	1.4	0
Mar.	11	13	22.9	15	12.4	0	2.7	0
Apr.	17	11	18.0	13	18.2	5.2	4.6	0
May	22	9	49.5	20	25.5	5.5	6.6	0
June	27	2	24.2	5	35.9	30.9	9.9	4.9
July	30	2	4.2	2	45.5	43.5	12.3	10.3
Aug.	29	1	1.5	1	42.0	41.0	11.4	10.4
Sept.	25	1	16.9	1	30.8	29.8	8.3	7.3
Oct.	21	2	11.4	3	23.8	20.8	6.1	3.1
Nov.	11	4	6.8	4	12.4	8.4	2.7	0
Dec.	5	5(4)	13.9	5(4)	8.3	3.3	1.4	0

(1) Mean monthly air temperature plus 6° F.

(2) Assuming 85% reduction in B.O.D. of Emporia sewage by treatment; minimum dissolved oxygen residual below Emporia of 3 p.p.m.; 95% D.O. saturation and 1 p.p.m. 5-day 20°C B.O.D. in the diluting water; and zero D.O. in the sewage. Computations based on first stage biochemical oxygen demand.

(3) By Streeter-Phelps formula assuming K_1= 0.1 and K_2=0.1 at 20°C.

(4) Discharge affected by ice.

(5) Gaging stations near Elmdale and at Cottonwood Falls.

Table 14 Dissolved Oxygen at Critical Point in Cottonwood River below Emporia under Regulated Low Flow Conditions.

Month	Flows - C.F.S.			Dissolved Oxygen (2) at Critical Point - p.p.m.
	7-day low(1)	From Marion Reservoir	Total	
Jan.	2	0	2	4.9
Feb.	8	0	8	9.7
Mar.	13	0	13	8.5
Apr.	11	0	11	6.3
May	17	0	17	6.0
June	4	20	24	5.4
July	2	20	22	4.6
Aug.	1	20	21	4.7
Sept.	1	20	21	5.7
Oct.	3	10	13	5.5
Nov.	3	10	13	8.5
Dec.	4	0	4	7.8

(1) Record 7-day low flows at Elmdale and Cottonwood Falls Gaging Stations corrected for reduction in unregulated drainage area due to Marion Reservoir.

(2) Assuming 85% reduction in B.O.D. of Emporia sewage by treatment; 95% D.O. saturation and 1 p.p.m. 5-day 20° C. B.O.D. in the diluting water; and zero D.O. in the sewage. Residual D.O. computed on basis of Streeter-Phelps formula using $K_1 = 0.1$ and $K_2 = 0.1$ at 20° C, respectively.

dissolved oxygen concentration expected is 4.6 p.p.m. which is sufficient to maintain satisfactory stream conditions.

Should times of flow between the Marion Reservoir and Emporia under low flow conditions be such as to require compensation, the releases at Marion Reservoir may be advanced to provide for this. Computations simulating an advance of a month in releases indicate that the above flows can be provided under this condition.

(b) Neosho River - Maintenance of adequate quantities for water supplies taken from the Neosho River necessitates that a continuous release to the Neosho River be included in any plan of operation. Considering quality and practicability, this release should be secured from the Council Grove Reservoir. A continuous release of 10 c.f.s. would be sufficient for this purpose.

A comparison of treated sewage loadings of the municipalities located on the Neosho River (Table 12) indicates that the most critical points of oxygen depression would occur in the relatively congested section between Iola and Erie. Investigation of oxygen depression in each of the river stretches between municipalities in this section indicates the most critical point to be below Chanute. Chanute has, therefore, been used as a basis of detailed investigation.

The amounts of dilution required to insure a minimum 3 p.p.m. dissolved oxygen content below Chanute are shown in Table 15, computed both on a basis of straight dilution (excluding reoxygenation) and on the basis of a conservative rate of reaeration (K_2 = 0.1 at 20°C. in the Streeter-Phelps formula).

A comparison of those requirements with the 7-day low flows of record at Iola (Table 15) shows flow deficits during June to November, inclusive, on a straight dilution basis and June to September, inclusive, considering reaeration.

Considering the critical period June to September, inclusive, and the desirability of maintaining a minimum of 10 c.f.s. at all times for water supply purposes, regulated releases from the maximum conservation storage at Council Grove Reservoir were determined, which, supplemented by the controlled flow from the Cottonwood River, should provide reasonable results from the standpoint of water supply and pollution control in the Neosho River. Two alternatives in Council Grove releases were investigated under this plan of operation. These releases are shown in Table 16. This plan is further discussed in the following section.

Table 15 Record Low Flows in Neosho River and Theoretical Dilution Flows Required to Provide 3 p.p.m. Dissolved Oxygen at Critical Point below Chanute.

Month	Stream Temp. °C.(1)	Lowest Flow of Record (4) - C.F.S.			Min. Dilution Flow Required at Chanute - C.F.S. (2)			
					Neglecting Reaeration		With Reaeration(3)	
		Day	Month	7-day period	Required	7-day deficit	Required	7-day deficit
Jan.	5	12	28.1	21	10.6	0	1.9	0
Feb.	5	12	30	19	10.6	0	1.9	0
Mar.	11	24	74	32	15.7	0	3.5	0
Apr.	17	31	67.8	40+	23.6	0	6.0	0
May	22	31	312	40+	32.8	0	8.7	0
June	27	1	126	2	46.3	44.3	12.7	10.7
July	30	1	16.1	2	58.2	56.2	16.0	14.0
Aug.	29	0	1.1	0	54.0	54.0	14.8	14.8
Sept.	25	0	26.5	0	39.8	39.8	10.9	10.9
Oct.	21	6	29.3	18	30.6	12.6	8.0	0
Nov.	11	9	15.7	14	15.7	1.7	3.5	0
Dec.	5	14	21.2	14	10.6	0	1.9	0

(1) Mean monthly air temperature plus 6° F.

(2) Assuming 79% composite reduction in B.O.D. of Chanute municipal sewage and industrial wastes unconnected to city sewers; minimum dissolved oxygen residual below Chanute, 3 p.p.m.; 95% D.O. saturation and 1 p.p.m. 5-day 20°C. B.O.D. in the diluting water; and zero D.O. in the sewage. Computations based on first stage biochemical oxygen demand.

(3) By Streeter-Phelps formula assuming $K_1 = 0.1$ and $K_2 = 0.1$ @ 20°C.

(4) Gaging station at Iola.

Table 16 Dissolved Oxygen at Critical Point in Neosho River below Chanute under Regulated Low Flow Conditions, Plan A-1 and Plan A-2.

Month	Regulated Flow from Marion Res. (at Emporia)(1) c.f.s.	Unregulated 7-day low flow at Iola (2) c.f.s.	Plan A-1			Plan A-2		
			Flow from Council Grove c.f.s.	Total Dilution Flow c.f.s.	D.O.at Critical Point p.p.m(3)	Flow from Council Grove c.f.s.	Total Dilution Flow c.f.s.	D.O. at Critical Point p.p.m.(3)
Jan.	0	18	20	38	11.5	10	28	11.3
Feb.	0	17	20	37	11.5	10	27	11.3
Mar.	0	28	10	38	9.6	10	38	9.6
Apr.	0	40	10	50	8.2	10	50	8.2
May	0	45	10	55	7.2	10	55	7.2
June	20	2	20	42	5.9	30	52	6.1
July	20	2	20	42	5.3	30	52	5.5
Aug.	20	0	20	40	5.4	30	50	5.8
Sept.	20	0	20	40	6.2	30	50	6.5
Oct.	10	16	15	41	7.1	10	56	7.0
Nov.	10	12	15	37	9.6	10	32	9.4
Dec.	0	14	20	32	11.4	10	22	11.0

(1) Regulated Marion Reservoir discharges at Emporia (natural flow accounted for in Iola 7-day lows.)

(2) Record 7-day low flows at Iola gaging station corrected for reduction in unregulated drainage area due to Marion and Council Grove Reservoirs.

(3) Assuming 79% composite reduction in B.O.D. of Chanute municipal sewage and industrial wastes unconnected to city sewers; 95% D.O. saturation and 1 p.p.m. 5-day 20°C. B.O.D. in the diluting water; and zero D.O. in the sewage. Residual D.O. computed on basis of Streeter-Phelps formula using $K_1 = 0.1$ and $K_2 = 0.1$ at 20°C. respectively.

Plans (A & B) of Reservoir Operation

Plan A - Council Grove and Marion - Two alternatives are offered under a two-reservoir plan, both of which utilize the full conservation storage capacities of 27,500 acre-feet and 47,000 acre-feet at Marion and Council Grove, respectively.

Plan A-1 - Under this method of operation seasonal releases (Table 16) from Council Grove are set up which will synchronize reasonably with the Marion reservoir releases, as fixed by Emporia conditions previously described. These releases, together with the uncontrolled flow will provide a more or less even distribution of controlled flow over the entire year, providing up to about 42 c.f.s. during the critical summer period, and allowing a minimum dissolved oxygen depression below Chanute of 5.3 p.p.m.

Computed dissolved oxygen residuals under these conditions at the critical point below Chanute for each month are shown in Table 16.

Should times of flow between the mouth of Cottonwood River and points of use at and below Iola be such as to require moving ahead upstream releases, Council Grove operation could be so synchronized. The releases from Marion, however, fixed in point of time and distribution by Emporia conditions should not be advanced. For at least a part of the summer critical period, the burden of dilution flow would then fall on Council Grove releases alone. Under these conditions a total of 22 c.f.s. would be available at Chanute until such time as the flow from Marion made itself felt. At 22 c.f.s. the dissolved oxygen residual below Chanute would reach a minimum of 4.0 p.p.m.

Plan A-2 - The Council Grove releases under this plan (Table 16) would provide a maximum of dilution for the period June to September, inclusive. The residual dissolved oxygen values below Chanute, omitting time of flow considerations, are shown in

Table 16. In comparison with Plan A-1, this method of operation would result in somewhat higher dissolved oxygen residuals during the critical months. Considering times of flow, Council Grove releases of 30 c.f.s. for at least the first part of the critical season would provide improved oxygen conditions as compared with Plan A-1. The minimum dissolved oxygen below Chanute under these conditions (32 c.f.s.) would be about 4.8 p.p.m.

The increases in low flows in the Grand (Neosho) and the Cottonwood Rivers under Plan A (1 and 2) are shown in Table 17. Under both plans the flow in the Cottonwood River would be the same. Although the minimum flows in the Grand (Neosho) at Iola and Parsons would be lower under (2) than under (1), these low flows would occur during the winter months when the need for dilution to prevent oxygen depletion is at its lowest. Of the two, Plan A (2) appears preferable.

Table 17 Percentage of Time when Flows would be Less than Specified Amounts with and without Regulation from Council Grove and Marion Reservoirs

Flow Under	Neosho River						Cottonwood River at Elmdale-Cottonwood Falls ***	
	At Iola *			At Parsons **				
	Unregulated	Regulated Plan A		Unregulated	Regulated Plan A		Unregulated	Regulated
		1	2		1	2		
c.f.s.								
5	1.5	0	0	1.6	0	0	3.4	0.4
10	2.0	0	0	1.8	0	0	7.3	0.7
15	3.4	0	0	2.1	0	0	12.6	3.4
20	4.6	0	0	3.2	0	0	18.8	7.7
25	6.9	0	0.2	4.7	0	0	25.6	14.8
30	8.9	0	0.5	6.4	0	0.3		
40	13.7	0.8	2.7	9.2	0.3	1.2		
50	17.7	5.9	6.7	12.0	3.7	3.8		

* Period of record November 1917 - September 1938.
** Period of record November 1921 - September 1938.
*** Period of record May 1922 - September 1938.

Plan B - Iola with Marion and Council Grove - Under Section One (E), the proposed water development plan for the Grand (Neosho) River in Kansas includes, in addition to the Council Grove and Marion Reservoirs, a flood control project at Iola. A minimum flow of 50 c.f.s. at all times could be maintained at and below Iola by providing 10,000 acre-feet of conservation storage in Iola flood control reservoir. With storage at Iola, conservation storage in the Council Grove reservoir could be reduced from 47,000 acre-feet (Plan A), to 20,000 acre-feet, which would be sufficient to maintain the continuous release of the 10 c.f.s. for assurance of water supply adequacy. Marion Reservoir would remain unchanged under this plan.

With 50 c.f.s. from Iola Reservoir available as a continuous release it is apparent that release synchronization and time of flow complications are eliminated, with the resulting assurance of an adequate dissolved oxygen residual at all times.

Comparison of Plans - A comparison of Plan B with Plan A (1 & 2) indicates that the complications in release synchronization from the upstream reservoirs will be eliminated. Dilutions obtained under Plan B will be comparable to the best conditions secured under Plan A. Flow control with Iola would improve the chemical quality of downstream water supplies.

(C) Chemical Pollution

(1) Oil Brine

Oil field brines enter tributaries of both the Neosho and Cottonwood Rivers. The estimated quantities and strengths of the brine produced in the basin are indicated by stream sections in Table 18. The chloride content of the Neosho at Iola, St. Paul and Oswego for the years 1934-38 is shown in Tables 19. These data indicate that the average chloride content is not high, although high concentrations have been found due to short time discharges of large quantities of brine.

In the basin disposal of brine is accomplished by reinjection into subsurface strata and by discharge into storage or evaporation ponds. Reinjection is the preferred method and is generally used in those areas requiring repressuring, especially where surface water is not available. The use of storage or evaporation ponds is not entirely satisfactory as the evaporation rates for brine waste are very low and disposal of the brine is contingent upon either seepage into the ground or diversion to surface streams during high stages.

Table 18 Estimated producing oil wells, with quantity and quality of brines, produced, expressed by watershed divisions for that portion of the Grand (Neosho) River Basin above the Oklahoma-Kansas State Line. (From basic data Kansas State Board of Health).

Watershed Division	River Mileage	Estimated No. Producing Wells	Daily bbls. Brine Waste			Volume of Brine on Watershed		Average Chloride Content p.p.m.
			Total	Reinjected	To Evap. Ponds	Mean c.f.s.	Acre-feet per day	
Okla-Kans. line to Iola Dam Site	60	6000	60,000	15,000	45,000	2.925	5.800	10,000
Iola to Cottonwood River Confluence	48	1800	5,400	1,400	4,000	0.260	0.516	30,000
Cottonwood River	70	150	6,000	3,000	3,000	0.195	0.387	40,000
Neosho above Cottonwood	45	-	-	-	-	-	-	-
Totals	-	7950	71,400	19,400	52,000	3.380	6.703	33,400*

* Weighted average.

Table 19 Chlorides, in ppm, in Grand (Neosho) River at Iola, Oswego and St. Paul, Kansas, expressed for various flows.

Year		Chlorides in p.p.m. for Flows of: 0-25 c.f.s.	26-50 c.f.s.	51-100 c.f.s.	101-300 c.f.s.	301-500 c.f.s.	501-1000 c.f.s.	Over 1000 c.f.s.
Iola 1934	Maximum	282	590	1200	475	365	180	610
	Minimum	45	61	48	65	17	180	150
	Average	90	170	280	158	178	180	305
Iola 1935	Maximum	-	166	135	160	34	22	211
	Minimum	-	89	42	6	34	22	12
	Average	-	128	76	59	34	22	61
Iola 1937	Maximum	64	81	214	227	108	52	105
	Minimum	40	29	21	20	18	12	12
	Average	53	64	75	76	50	30	50
Iola 1938	Maximum	57	30	65	161	115	109	60
	Minimum	16	17	65	18	64	31	10
	Average	31	23	65	81	89	53	25
*Weighted Average:		58	109	141	84	95	45	69

* Computed in proportion to number of Samples.

Table 19a. Chlorides, in ppm, in Grand (Neosho) River at Oswego and St. Paul, Kansas, expressed for various flows.

Year		Chlorides in p.p.m. for Flows of: 0-25 c.f.s.	26-50 c.f.s.	51-100 c.f.s.	101-300 c.f.s.	301-500 c.f.s.	501-1000 c.f.s.	Over 1000 c.f.s.
Oswego	Maximum	40	65	94	120	44	65	265
1934	Minimum	18	14	8	6	31	28	37
	Average	28	42	53	52	38	49	122
Oswego	Maximum	-	53	100	64	40	124	121
1935	Minimum	-	45	18	10	9	26	9
	Average	-	49	50	38	28	56	32
*Weighted Average		28	44	52	43	30	54	54
St. Paul	Maximum	43	34	112	58	125	29	82
1937	Minimum	40	25	22	30	17	29	19
	Average	42	30	48	42	56	29	46
St. Paul	Maximum	-	34	28	95	142	61	101
1938	Minimum	-	25	25	33	44	23	12
	Average	-	30	27	59	65	34	39
*Weighted Average		42	30	42	50	62	33	42

* Computed in proportion to number of samples.

(2) Mine Waste

The bituminous coal mining area in southeastern Kansas is shown in Figure 4. Acid drainage from these mines and wastes resulting from washing operations have been the cause of numerous complaints. Several tributary streams are highly acid. Very little has been accomplished in the abatement of acid mine drainage and coal washery wastes although a great deal of attention is being focused on this problem at the present time. One of the coal washeries has installed a by-products plant which recovers substantial quantities of slack coal and pyrites. (Metal mine waste discussed under Problem 5, subhead C.)

Problem (IV) Determine the estimated monetary value of conservation storage in the reservoirs, on an acre-foot basis, for stream pollution control and municipal water supply use.

(A) Summary of Conclusions

(1) The tangible monetary values of conservation storage for water supply use and pollution control are computed to be:

(a) Marion-Council Grove Reservoir System - Value per acre-foot - $35.00

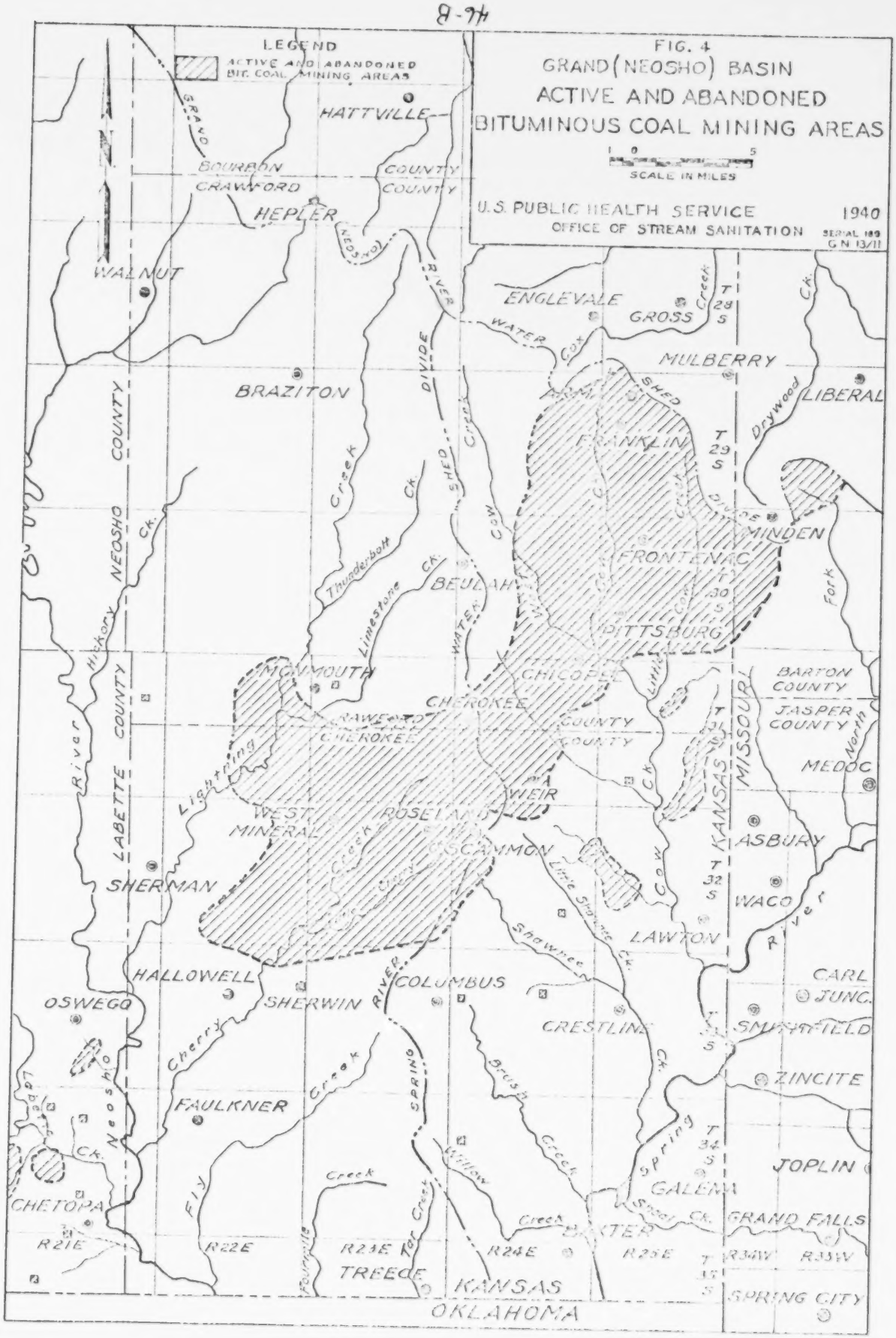
(b) Marion-Council Grove-Iola Reservoir System - Value per acre-foot - 45.00

(2) The indicated monetary benefits represent the minimum values of reservoir development inasmuch as numerous incalculable improvements, as discussed in the report, are not invoiced monetarily in the computed estimates.

(B) Discussion of Problem

(1) General

Low flow augmentation by the installation and operation of conservation storage in the tri-reservoir system, as set up in Problem (III), is extremely desirable and would be of definite benefit to a well balanced water use program for the basin. Outstanding among the beneficial effects of such low flow regulation and conservation storage are:


LEGEND
ACTIVE AND ABANDONED BIT. COAL MINING AREAS
FIG. 4
GRAND (NEOSHO) BASIN
ACTIVE AND ABANDONED
BITUMINOUS COAL MINING AREAS
SCALE IN MILES
U.S. PUBLIC HEALTH SERVICE 1940
OFFICE OF STREAM SANITATION
HATTVILLE
HEPLER
WALNUT
BRAZITON
ENGLEVALE
GROSS
MULBERRY
LIBERAL
MINDEN
FRONTENAC
PITTSBURG
MONMOUTH
CHICOPEE
CHEROKEE
WEST MINERAL
ROSEDALE
WEIR
SCAMMON
SHERMAN
ASBURY
WACO
LAWTON
HALLOWELL
COLUMBUS
SHERWIN
OSWEGO
CRESTLINE
CARL JUNC.
SMURFFIELD
ZINCITE
FAULKNER
CHETOPA
JOPLIN
GALENA
GRAND FALLS
TREECE
KANSAS
SPRING CITY
OKLAHOMA
BOURBON COUNTY
CRAWFORD COUNTY
LABETTE COUNTY
NEOSHO COUNTY
CHEROKEE COUNTY
BARTON COUNTY
JASPER COUNTY
R21E
R22E
R23E
R24E
R25E
R34W
R33W
T 28 S
T 29 S
T 30 S
T 31 S
T 32 S
T 34 S
T 35 S

(a) Assured quantity of improved quality water for municipal and industrial needs.

(b) Maintenance of satisfactory oxygen relations by providing adequate dilutions for properly treated organic wastes.

(c) Providing a suitable habitat for aquatic life by assurance of minimum flows and prevention of serious oxygen depletions in critical zones of depression.

(d) Improvement of recreational facilities and provision of migratory water fowl havens.

(e) Established continuous flow for normal riparian and agricultural uses, including stock watering and possibly some restricted irrigation.

(f) Dilution for small amounts of uncontrolled oil field brine that will inevitably reach watercourses even in the best controlled oil field areas.

Experience has shown that attempts to calculate a monetary value for these benefits introduces an array of variable and controversial factors which renders an equitable solution impractical. Consistent with available data, it appears practical to develop minimum tangible benefits that would accrue to (a) public water supplies and (b) organic pollution abatement should the proposed conservation reservoir system materialize.

(2) Tangible Public Water Supply Benefits

Discussions under Problem (II) portray the need for

supplemental sources of surface water as necessary protection against periodic droughts. Within economic limitation, the only available source of water supply for bordering municipalities is the Grand (Neosho) River and its tributaries. A practical method of computing the minimum tangible monetary value of low flow augmentation for water supply use involves determining the cost of duplicating the afforded minimum protection by channel or off-channel impoundments at the individual cities. Ample precedent for this approach exists in the basin itself.

Following the 1936 drought many of the cities expended large sums in an effort to thwart a recurrence of the disastrous water shortages experienced during that and previous years. Unsuccessful efforts, at considerable expense, were made to develop supplemental underground water supplies.

Emporia, Kansas (mile 398) at an expenditure of $270,000, constructed an impounding reservoir on Kahola Creek to supplement Grand (Neosho) River flows. There appears some doubt as to the adequacy of this storage and consideration has been given to installing a 14-mile pipe line connecting the impoundment with the Emporia treatment plant as a means of averting channel losses in Kahola Creek. The cost of this

pipe line project has been estimated at $500,000. The minimum individual expenditure for providing assured water supply at Emporia is the cost of an additional tributary impoundment above the city. Analysis of survey data coupled with cost of similar capacity impoundments in the area indicates this reservoir cost at approximately $300,000.

Council Grove, Kansas (mile 447) is at present considering the construction of an impounding reservoir with a 12 square mile catchment area and a storage capacity of about 8,000 acre-feet. This proposed development is on Canning Creek, a small Grand (Neosho) River tributary. The detailed cost estimate of this project is $260,000 and it will not provide assured flows comparable to the proposed Council Grove reservoir.

Disregarding silting, bordering municipalities from Iola (mile 292) downstream can apparently insure an adequate quantity of water by providing one or more low-channel dams of from 100 to 200 acre-feet capacity. Some of the communities now have these channel impoundments. From analysis of collected data and consultation with state officials, the minimum necessary expenditure of supplementing existing storage facilities at five municipalities from Iola (mile 292) to Oswego (mile 187), with additional channel impoundments as required for reasonable protection, would total above

$350,000. Existing safeguards against water shortages are fairly adequate at the other water supply intakes along the Grand (Neosho) River.

Inasmuch as local impoundments, if feasible from an engineering standpoint, would not insure quantities and qualities of water comparable to the proposed reservoir releases, this method must be considered as representing the absolute minimum tangible benefit.

(3) Organic Pollution Abatement Benefits

Sources of organic pollution discharging direct to the Grand (Neosho) River were considered in detail in Problem (III), together with seasonal dilutions that would, when combined with stipulated treatment, avoid odorous nuisances and maintain satisfactory dissolved oxygen relations through critical zones of oxygen depression.

The method of computing the tangible monetary value of conservation storage as related to organic pollution abatement involves determining cost of necessary supplemental treatment, as tertiary units, that would produce stable effluents. The supposition of this approach is that organic pollution in the Grand (Neosho) River channel will be controlled either by waste treatment plus regulated minimum

flows or by refined waste treatment alone. As related to sewage disposal, the cost of completing the oxidation process, by substituting tertiary waste treatment units for diluting water, would represent the minimum tangible monetary value of adjudicated conservation storage.

Organic pollution abatement and stream conditions as set up in Problem III are contingent upon the 14 sewered communities bordering the Grand (Neosho) River above the Oklahoma-Kansas line providing treatment equivalent to 5-day B.O.D. reduction of 85%. Supplemental treatment to produce relatively stable effluents was designed as intermittent sand filters.

Design figures used in the computations were based on consideration of influent waste to be treated, local conditions affecting cost, actual experience on similar problems in other sections and policy requirements of the Kansas State Board of Health in approving actual plans. Sand filters were designed on the basis of a 3-foot depth and loadings of 150,000 gallons per acre per day (loading rates based on policy requirement of Kansas State Board of Health). Price of filter sand was determined at $2.00 per cubic yard, f.o.b. destination. Chlorination of sand filter effluents was excluded from the designs inasmuch as the proximity of intakes

to outfalls is such that chlorination of treatment plant effluents appears indicated regardless of the degree of treatment.

(4) Summary Installation Cost

There follows a summary of the computed installation cost of providing water storage and supplemental treatment units for sources of organic pollution discharging direct to the Grand (Neosho) River above the Oklahoma-Kansas state line:

Off-channel storage Council Grove	- $260,000.00
Pipe line or impoundment Emporia (Minimum)	300,000.00
Channel Dams (For 5 Municipalities)	- 350,000.00
Intermittent sand filter units (14)	- 475,000.00
Land, Engineering and Contingencies	- 100,000.00
Total Installation Cost	1,485,000.00

(5) Summary of Annual Cost

Based on analysis of local data, the life expectancy of impoundments of the type proposed is considered as 30 years, and sewage treatment facilities at 15 years. Annual charges for individual solution of public water supply problems and tertiary treatment units for organic waste effluents are as

follows:

1.	Interest (5% of 1,485,000) -	$74,250.00
2.	Amortization of Obsolescence:	
	(a) Impoundments (.01505 x 910,000)	13,695.50
	(b) Sand Filters (.0463 x 475,000)	21,992.50
3.	Operations and Maintenance:	
	(a) Water Impoundments -	5,000.00
	(b) Supplemental waste treatment -	15,000.00
	Total Annual Value	$129,938.00
	Capitalized at 5%	$2,598,760.00

(6) Value of Conservation Storage

(a)	Plan A (Marion and Council Grove Reservoirs - total conservation storage 74,500 acre-feet) - per acre-foot -	$34.88
	Say -	$35.00
(b)	Plan B (Marion, Council Grove and Iola Reservoirs - total conservation storage 57,500 acre-feet) - per acre-foot -	$45.20
	Say	$45.00

(7) Intangible Benefits

Under Problem II, (sub-head B), it was indicated that reservoir operation would improve the chemical quality of the stream water. This is especially true in regard to total hardness. Hoover*, using Foulke's Formula, shows a

* Hoover, Charles P. "Water Supply and Treatment", National Mine Assoc., Washington, D. C. 1936.

saving in soap alone of $0.052 per ppm of hardness reduction for the average family per year. Shaw and Chase* assign a value of $0.41 per m.g. for removal of hardness over 100 ppm. With existing analytical data no direct calculation can be made of monetary benefits resulting from hardness reduction. To reduction in treatment cost would be added the economies effected in those communities whose treatment does not include softening. Industrial water supplies, whether from private or municipal intakes, will be correspondingly improved. Further savings would result from reduced fuel consumption, maintenance and repairs.

During extended periods of near zero flow, water supplies of municipalities below Iola are made up largely of sewage effluents from upstream outfalls. This continuous reuse of water after relatively short times of flow creates a potential public health problem of no little significance. Further, from an aesthetic sense, an indignant public reaction to use of sewage effluents as a source of drinking and culinary supply, regardless of artificial treatment and purification, has been noted in the basin. There exists no logical approach to invoice in dollars these hazards or

* Shaw and Chase, "Journal New England Water Works Assoc.," June 1939.

public sentiments. However, analysis of data from several cities, under similar circumstances, where bottled waters are sold for drinking purposes, indicates that about 30% of the population use such supplies at a cost near that of the metered supply. Applying these figures to the Grand (Neosho) River cities, and assuming an approved supply of bottle water was available for an average 4 months a year at only $.50 per 5 gallons, the average annual public expenditure would total above $25,000 per year.

Recreational values assigned to any particular project are purely relative. In localities with a plenitude of natural playgrounds, the value of an additional recreational facility is small and, conversely, as in the Grand (Neosho) Basin, where these facilities are lacking, any improvement in the recreational assets is of material value. Impoundment and low flow regulation would bring about better fishing conditions, will provide recreational diversions such as boating, bathing and fishing, and would benefit migratory water fowl.

Increased minimum flows would benefit agriculture by increasing the value of riparian farms, and providing

adequate stock water. The firm power capacity of the small hydroelectric projects located downstream from the Marion and Council Grove dam sites would be increased.

Problem (V) Determine the significance of stream pollution in the Spring and Elk (Cow Skin) River basins, practical control measures, and the value of conservation storage in the Waco and Neal Reservoirs for pollution correction.

(A) Summary of Conclusions

(1) Significant pollution of portions of the Spring River and tributaries results from the discharge of improperly treated sewage, organic industrial wastes, and acid drainage from coal and metal mines.

(2) Of the total organic load (population equivalent about 100,000) 90% reaches tributaries or the main stem above the Waco Reservoir site.

(3) Organic pollution can be effectively controlled by practical waste treatment methods, but no entirely satisfactory method for treatment of mine wastes has yet been developed. In general, promising corrective measures involve acid neutralization by the use of either chemicals or natural stream alkalinity with precipitation of iron and aluminum in off-channel impoundments.

(4) Low flow regulation from the Waco Reservoir would have no appreciable effect on organic pollution or coal mine drainage. However, low flow control may prove beneficial in potential treatment of metal mine wastes involving use of natural stream alkalinity. Beneficial use would be dependent on minimizing the diurnal fluctuation in river stages below the Lowell power dam.

(5) Low flow regulation from the Neal Reservoir on the Elk (Cow Skin) River would have no appreciable effect on the control of pollution.

(B) Discussion of Problem

(1) General

The Spring and Elk River Basins, draining 3,670 square

miles in Kansas, Oklahoma, Missouri and Arkansas, comprise gently rolling prairie in the northern portion and typical Ozark highland features in the eastern and southern portions. The narrow stream valleys are bordered by relatively steep slopes flanked by scattered small plateau areas. In Missouri and Arkansas, agriculture, including general farming, grain, dairying and fruit orcharding, is the principal occupation. The Elk basin is rougher, more heavily forested, and less developed agriculturally than the Spring. It is used extensively for recreation.

Industrial developments in the basins, are primarily those for processing of local agricultural products, with milk condenseries, cheese plants, packing plants, canneries, and creameries predominating. In the lower Spring Basin lead, zinc, and bituminous coal mining are of notable significance.

Hydrology, population distribution, and stream characteristics are covered in Section One of this report.

In the Spring River basin 30 public water supplies serve about 110,000 population and in the Elk River basin 3,600 persons are served by 5 systems. Excepting Joplin (population served 33,000) and Lamar (population served 22,000) in the Spring River basin, all municipalities use

underground water as a source of supply. Several aquifers, notably the Roubidoux, Gasconade, and Gunter, produce adequate quantities of water of generally good chemical quality for municipal and industrial use.

In the Spring River basin public sewerage systems serve 83,000 population in 19 municipalities; in the Elk Basin only one municipality, Bentonville, population 2,000, has a sewerage system with secondary treatment. In the Spring Basin 7 communities provide secondary treatment facilities and 6 other use primary units. Data on municipal water supplies, sewerage systems and waste discharges in the Spring and Elk Basins are tabulated in Table 9 and summarized in Table 10 (Section One, Subhead (D)).

Stream pollution reaches detrimental proportions in the upper and central reaches of the Spring River as a result of the discharge of inadequately treated sewage and putrescible industrial wastes into streams subject to very low flows, and in the lower portion due to chemical pollution from mine wastes.

(2) Elk (Cow Skin) River

The Elk (Cow Skin) River, an important recreational stream, has no large pollution problems, and minor local pollution can be controlled by well established methods of

waste treatment. Existent pollution is above the proposed Noel Reservoir and would not be benefited by low flow regulation from this impoundment.

(3) Spring River

An inspection of Table 9 and Figure 2-A (Spring River plate) shows that more than 90% of the sewage and organic industrial wastes in the Spring Basin is discharged either to tributary streams or to the main stream above the Waco dam site (mile S-47.7). Waste treatment adequate to solve local pollution problems at the various municipalities will eliminate almost entirely the effect of the wastes on the Spring River at and below the dam site. For example, at Joplin, Missouri, the largest city in the basin, municipal wastes are discharged to Turkey Creek, which joins the Spring River at mile S-35, below the Waco dam site. The stream pollution problem at Joplin is fundamentally one of grossly polluting Turkey Creek. With effective secondary treatment of Joplin wastes, as necessary to avert local nuisances, and the subsequent 8 to 10 mile flow in Turkey Creek before reaching Spring River, there would be no appreciable disturbance of the oxygen balance in Spring River.

Pollution due to acid drainage from bituminous coal

mines is not serious in the Spring River itself. Figure 4 shows the location of the coal field. Most of the area is drained by Cow Creek which is badly polluted in certain stretches.

Figure 5 shows the location of the mineralized areas in the Tri-State lead and zinc mining area. The Joplin-Webb City fields in Missouri are older and less extensively mined than the Oklahoma and Kansas fields near Picher, Oklahoma, and Baxter Springs, Kansas. Limited data indicate that mine waste pollution from the Missouri field causes only local problems and that it has no significant effect on the lower Spring River.

Large amounts of acid waste enter the Spring River directly or through small tributaries in the Kansas and Oklahoma sections of the metal mining area. At Baxter Springs, Kansas, about 7 tons of iron and aluminum and 15 tons of acid (computed as sulphuric acid) enter the Spring River daily. At times the stream is discolored by the precipitated ferric hydroxide for several miles.

Reproduced from best available copy.

Any proposed low flow regulation of the Spring River in the lead and zinc mining area by conservation storage in the Lake Reservoir must, in some way, be correlated with the operation of the Empire District power dam at Lowell to offset the diurnal fluctuations in river stages below the power development.

Detailed discussion of the lead and zinc mine waste problem follows under Subhead (C).

(C) Metal Mine Waste

(1) General Summary

(a) Chemical pollution by acid mine drainage from the Tri-State District is of definite significance in lower Spring River and Tar Creek.

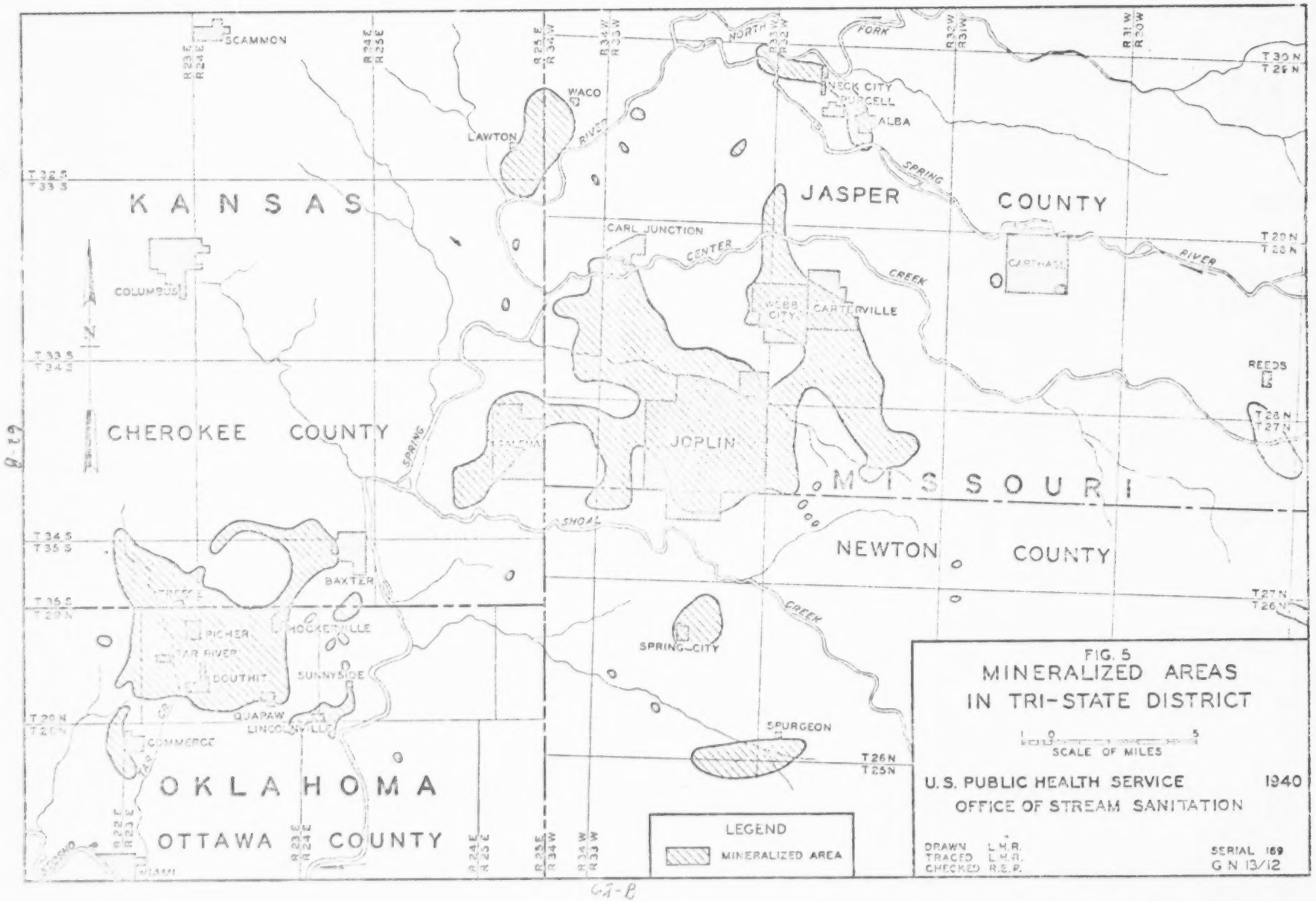
(b) Present pumpage of mine water totals approximately 5.4 M.G.D., with 4.0 M.G.D. tributary to Tar Creek and 1.4 M.G.D. tributary to Spring River. Full development of mining operations will probably result in an increase in mine waste up to about 40%. Acidity values range up to 3,920 ppm; pH values from 2.8 to 7.35, and iron up to 1,060 ppm. Daily chemical stream loadings total approximately 8 tons of iron and aluminum and 17 tons of acidity, of which 7 tons of iron and aluminum and 15 tons of acidity are tributary to Spring River.

(c) Equitable methods of controlling pollution of streams appear to include one or more of the following: (a') impoundment and treatment by chemicals; (b') impoundment and dilution by river water with attendant neutralization of acidity by natural alkalinity; (c') sealing of surface cracks and caves in active and abandoned mines to minimize entry of surface water and (d') sealing of abandoned mines to prevent entry of air which is essential to acid formation.

Because of cost, method (a') will be limited in its application to those cases involving low quantity and acidity. Method (b') offers the most promise where large quantities of water with high acidities are involved. Methods (c') and (d') will serve only to mitigate the pollution problem, not solve it.

(2) Introduction

A significant industrial pollution problem is caused by mine waters from the Tri-State lead and zinc mines.


KANSAS
OKLAHOMA
MISSOURI
CHEROKEE COUNTY
OTTAWA COUNTY
JASPER COUNTY
NEWTON COUNTY
SCAMMON
WACO
LAWTON
COLUMBUS
CARL JUNCTION
WEBB CITY
CARTERVILLE
JOPLIN
NECK CITY
PURCELL
ALBA
CARTHAGE
REEDS
BAXTER
TREECE
PICHER
HOCKERVILLE
TAR RIVER
DOUTHIT
SUNNYSIDE
QUAPAW
LINCOLNVILLE
COMMERCE
SPRING CITY
SPURGEON
NORTH FORK RIVER
SPRING RIVER
CENTER CREEK
SHOAL CREEK
LEGEND
MINERALIZED AREA
FIG. 5
MINERALIZED AREAS
IN TRI-STATE DISTRICT
SCALE OF MILES
U.S. PUBLIC HEALTH SERVICE 1940
OFFICE OF STREAM SANITATION
DRAWN L.H.R.
TRACED L.H.R.
CHECKED R.E.P.
SERIAL 169
G N 13/12

As these waters are acid, the alkalinity of the larger receiving streams is reduced, and the alkalinity of smaller streams may be completely neutralized resulting in acid conditions. The mine waters also contain considerable quantities of acid salts of iron and aluminum which are precipitated by the alkalinity and oxygen in the streams resulting in objectionable discoloration and suspended matter.

Mine waste pollution is particularly acute at the time of reopening a mine due to the heavy pumping necessary to dewater flooded workings.

(3) Mining Operations

The Tri-State Mining district, located in southeastern Kansas, southwestern Missouri and the adjacent area in northern Oklahoma, includes one of the world's largest lead and zinc ore deposits. Mining operations have been substantially continuous since the District opened near Galena, Kansas, in 1876. Original developments in the Kansas-Missouri area have been largely depleted with principal activity since 1914 in the Kansas-Oklahoma fields near Picher, Oklahoma.

Figure 5 shows location and extent of mineralized areas in the Tri-State district in relation to stream drainage. In this district ore deposits, intermingled with chert of the

Boono-Mississippian Age, occur largely in runs with some deposits of the blanket or "sheet ground" type.

In mining operations vertical shafts are sunk to the ore bearing strata and drifts following the ore deposits are mined radially, with raises driven in instances where ore deposits are distributed vertically. Milling operations include crushing, jigging, tabling and flotation. The tailings pass from the mills and are conveyed to nearby tailings piles.

Production statistics for the Tri-State district, by states, for 1938 are shown in Table 20.

Table 20 Production and Value of Concentrates, for 1938 in the Tri-State District.

State	Lead Concentrate: Short tons	Value	Zinc Concentrate: Short Tons	Value
Kansas	19909	$1,023,851	133546	$ 4,132,248
Missouri	4234	212,858	19496	578,020
Oklahoma	27608	1,446,058	208484	6,390,422
Totals	51751	$2,682,767	361526	$11,100,690

The total value of the concentrates for 1938 was $13,783,457 corresponding to a recovered metal value of $22,457,504. Based on an average total concentrate recovery of 6.65%, the ratio of ore handled to concentrate recovered is approximately 15 to 1. A man-day of labor averages 0.43 tons of concentrate or 6.57 ore-tons.

(4) Mine Water

Incidental to active mine operation, it is necessary that the mine be kept free of water which is encountered to some extent in all mines. Common practice includes construction of a sump from which mine drainage is pumped to ground surface.

The chemical quality of mine waters varies considerably for different mines, being influenced largely by extent and location of pyrites and marcasites in relation to mine seepages in the presence of air. In general, acidities range to about 4,000 p.p.m., total iron up to about 1,000 p.p.m., with pH from 2.8 to 7.3. In some instances this acidity is due to hydrolysis of iron and aluminum salts, in others the water actually contains free sulphuric acid.

The presence of acid salts of iron and aluminum and free sulphuric acid results from action of water and oxygen

(air) on pyrite and marcasite and the reactions may be expressed as:

(a) $2FeS_2 + 7O_2 + 2H_2O = 2FeSO_4 + 2H_2SO_4$

(b) $4FeSO_4 + 2H_2SO_4 + O_2 = 2\ Fe_2(SO_4)_3 + 2\ H_2O$

These salts of iron and aluminum are all substantially hydrolyzed in solution producing sulphuric acid and the corresponding hydroxide. Therefore, even in the absence of any so called free sulphuric acid, water containing large quantities of iron and aluminum sulphate would be definitely acid. From the standpoint of chemical pollution in receiving streams, the presence of acid salts of iron and aluminum and sulphuric acid in the mine waters is of definite significance.

The quantity of water pumped from the different mines varies over wide ranges. Estimates by field investigations of active mines indicate present daily quantities to average from about 0.1 to 1.0 million gallons per mine. The most serious situation as regards quantity and subsequent pollution arises as a result of shutdowns. In such instances reopening the mine necessitates continuous pumping at high rates for considerable periods of time to dewater the workings.

(5) Pollution Problems

Pollution by mine wastes may be considered from two angles, namely that resulting from the acidity and atton-

dant alkalinity destruction and that due to precipitation of iron and aluminum hydroxides resulting in discoloration and an increased suspended matter load in the stream.

The deleterious effect of acidity on receiving streams is due to diminution or complete destruction of the natural alkalinity. The destruction of alkalinity is accompanied by a decrease in pH, a temporary increase in carbon dioxide lost by dispersion, a decrease in carbonate hardness, and an increase in non-carbonate hardness. The total hardness is not significantly changed unless considerable iron and aluminur stay in solution, a condition not likely to persist.

The action of mine water acid substances on natural alkalinity, as calcium bicarbonate, may be expressed:

(a) $FeSO_4 + Ca(HCO_3)_2 = Fe(OH)_2 + 2CO_2 + CaSO_4$

(b) $4Fe(OH)_2 + O_2 + 2H_2O = 4Fe(OH)_3$

(c) $Fe_2(SO_4)_3 + 3Ca(HCO_3)_2 = 2Fe(OH)_3 + 6CO_2 + 3Ca\ SO_4$

(d) $Al_2(SO_4)_3 + 3Ca(HCO_3)_2 = 2Al\ (OH)_3 + 6CO_2 + 3CaSO_4$

(e) $H_2SO_4 + Ca(HCO_3)_2 = CaSO_4 + 2CO_2 + 2H_2O$

As indicated by equations (a), (b), (c), (d) and (e), iron and aluminum salts, reacting with stream alkalinity, form the corresponding ferric and aluminum hydroxides. These are quite insoluble and will readily flocculate and settle in quiescent water. The ferrous hydroxide formed by equation (a) is green in color but is oxidized by the dissolved oxygen in the water to ferric hydroxide, $Fe(OH_3)$, equation (b), which has the red color commonly associated with iron rust. Aluminum hydroxide is white.

Since the oxidation of ferrous hydroxide requires dissolved oxygen, the possibility of oxygen depletion is also a factor in the discharge of iron bearing acid mine water to streams.

The following table of equivalents is given as a guide to quantitative relationships.

	Parts alkalinity as $CaCO_3$ destroyed	Parts CO_2 Produced and Released	Parts carbonate hardness destroyed	Parts non-carbonate hardness formed.
1 part acidity as H_2SO_4	1.02	0.898	1.02	1.02
1 part ferrous sulphate as (Fe++)	1.79	1.58	1.79	1.79
1 part ferric sulphate as (Fe+++)	2.69	2.37	2.69	2.69
1 part aluminum sulphate as (Al+++)	5.56	4.89	5.56	5.56

Each part of ferrous sulphate expressed in terms of (Fe++) requires 0.143 part oxygen. Neither ferric iron nor aluminum have any oxygen requirements.

No simple equation can be given for the extent to which the pH of the receiving stream will be lowered. In the event quantity and quality of mine water is such as to neutralize all natural stream alkalinity, the resultant pH may be in the range of about 2.0 to 5.0. If natural alkalinity is not entirely neutralized, the pH may be lowered to the range of about 5.0 to 7.0.

In connection with chemical pollution by mine wastes Ellis considers that the "chat" (tailings) piles, are an added source of pollution. In Ellis'* report, it is stated that these "chat" piles contain varying quantities of several metallic sulphides, particularly those of iron, lead and zinc and that leaching of these piles by slow rains and melting snows, together with water pumped from active mines, results in the formation of acid water (pH range 3.8 to 6.2) which contains ingredients toxic to fish life.

(6) Field Investigations

Within time limitations, field work included collection of data on quantity and quality of acid mine waste and

* Ellis, M.M. "Report on the Pensacola Dam Impoundment on the Grand River with Special Reference to Fishery Problems in the Completed Reservoir," Special Scientific Report #4, Bureau of Fisheries, Department of Interior.

basic data as to potential solution of the problem.

Analytical data on samples collected from various active mines in the district, together with present average pumpage rates, are shown in Table 21.

Based on these data, the daily quantity of chemical wastes, classified according to the ultimate receiving stream, is shown in Table 22. A potential average daily load of approximately 2 tons of sulphuric acid and about 1.7 tons of iron and aluminum hydroxides is tributary to Tar Creek. Assuming all iron to be in the ferrous state the oxygen demand of the daily iron load would be 178 pounds. Assuming an alkalinity value of the diluting water of 100 p.p.m. as $CaCO_3$, a stream flow of approximately 10 c.f.s. would be needed to neutralize acidity and leave a residual alkalinity of approximately 10 p.p.m.

Tributary to Spring River, the potential daily load of acidity expressed in terms of sulphuric acid is approximately 15 tons, with a daily load of iron and aluminim hydroxides of approximately 1¼ tons. The oxygen demand of the iron, in the ferrous state, is 1610 pounds. Based on the previously assumed alkalinity conditions the dilution water needed for acid neutralization would be approximately 65. c.f.s.

Table 21 Quality and Quantity of Water Pumped from Various Mines in Tri-State District. (Stations 22 and 23 Discharged to Spring River; all other stations to Tar Creek).

Station	pH	Alkalinity as $CaCO_3$ (p.p.m.)	Acidity as H_2SO_4 (p.p.m.)**	Total Iron (p.p.m.)	Aluminum (p.p.m.)	Average Pumpage M.G.D.
1	2.85	0	1053	364	53	0.266
3	4.5	0	338	79	27	0.158
4	--	--	338*	79*	27*	0.144
6	6.75	234.	0	8.1	11	0.729
8	7.35	200.	0	1.8	--	1.15
10	7.05	130.	0	2.1	--	.576
11	7.25	228.	0	4.5	--	.166
12	6.0	100.	0	55.	24)	
13	7.25	236.	0	15.	11)	.072***
14	6.05	48.	0	69.	18)	
16	7.4	204.	0	13.	6.9	.72
21	3.25	0.	866	55.	26.	.096
						4.077
22	2.8	0	3920	1060	342	.429
23	3.6	0	2090	960	121	.935
						1.364

* Estimated -- Not determined.

** Titration at boiling temperature; phenolphthalein indicator.

*** Total for 3 pumps.

Table 22 Daily Chemical Load Due to Mine Wastes From Various Mines in Tri-State District (Stations 22 and 23 Tributary to Spring River; all others to Tar Creek.)

Station	Tons/day alkalinity as $CaCO_3$	Tons/day acid as H_2SO_4	Tons/day iron as such	Tons/day aluminum as such
1	0.	1.170	0.404	0.059
3	0.	0.223	0.052	0.018
4	0.	0.203	0.048	0.016
6	0.711	0.	0.025	0.033
8	0.959	0.	0.009	-----
10	0.312	0.	0.005	-----
11	0.158	0.	0.003	-----
12*	0.038	0.	0.014	0.005
16	0.612	0.	0.039	0.021
21	0.	0.347	0.022	0.010
Totals	2.790	1.943	.621	.162
			as $Fe(OH)_3$ 1.19	as $Al(OH)_3$ .47
22	0.	7.013	1.895	.613
23	0.	8.150	3.745	.472
Totals	0.	15.163	5.640	1.085
			as $Fe(OH)_3$ 10.8	as $Al(OH)_3$ 3.13

* Mean of 3 Samples (Stas.12-13-14).

(7) Sampling of Tar Creek and Spring River

Inasmuch as the quantity and quality of mine wastes vary over wide ranges the results of the limited sampling schedule followed on the streams proper present only an indication of the problems of mine waste pollution on a small receiving stream. Analytical data are shown in Table 23. The apparent discrepancy between the acid condition found in Tar Creek, Table 23, and the average alkalinity-acidity data computed in Table 22 probably results from short time high rate pumping of acid water preceding sampling of Tar Creek.

Table 23 Average Analytical Results of Samples Collected from Tar Creek and Spring River.

Station	Approx. Location	D.O.	pH	Alk.	Acidity	Fe	Al
	Tar Creek						
15	1 Mile North Okla. Line	-	7.2	82	0	1.2	-
17	1/4 Mile West Picher	-	7.25	76	0	.4	-
9	Below Station #1	7.4*	3.0	0	588	29	25
5	3 Miles below Picher	-	5.2	0	288	3.0	-
19	Bridge at Miami, Okla.	-	6.2	19	0	5.8	-
	Spring River						
26	Baxter Spgs. 12th St. Br.	7.5	7.2	124	0	3.2	-
7	1 Mile South Kans. Line	7.6	7.0	90	0	22	16

Stations in order of downstream locations.

*Average of two samples collected on 6/6 and 6/7.

(8) Potential Methods of Mine Pollution

As regards corrective measures the following are considered: (a) use of retention reservoirs with little or no treatment, (b) chemical treatment, (c) neutralization and precipitation by surface water alkalinity, (d) diversion of surface drainage from mines and (e) sealing.

Because of data limitations the problem approach was generalized in terms of quantities and costs of various chemicals required for treatment, quantity of sludge produced and flows needed for neutralization by surface waters of various alkalinities. At present the industry is making a study of the problem of mine waste pollution abatement and these data are given to assist in this connection.

(a) Retention Reservoirs - Because of the large volumes of mine waters involved, permanent impoundment in evaporating ponds appears infeasible. Several mines use retention reservoirs with controlled or uncontrolled diversion to natural drainage. From records of an operating company, analytical data on effluent and influent samples were secured to show chemical trends resulting from pondage. A small amount of lime was added to the raw waste. Based on averages of weekly samples over a 5-month period, these data are as follows:

Source	pH	Total Iron p.p.m.	Ferric Iron p.p.m.	Ferrous Iron p.p.m.
Raw mine water	3.8	926	206	720
Effluent from ponds	4.4	722	321	401
Reduction		204	115*	319
% Reduction		22	56*	44

Analytical results did not include acidity data.
* Increase.

From these data it must be concluded that no great benefit will be derived from the use of retention reservoirs.

(b) Chemical Treatment - The acidity of mine wastes may be neutralized by substances such as hydrated lime, $Ca(OH)_2$; quicklime, CaO; soda ash, Na_2CO_3; limestone (essentially $CaCO_3$ $MgCO_3$); and caustic soda, NaOH.

Products of neutralization include the sulphates corresponding to the positive ion of the neutralizing substance, ferric hydroxide, ferrous hydroxide, aluminum hydroxide, carbon dioxide and water. The carbon dioxide would be largely evolved to the atmosphere especially at points where the flow is turbulent. The ferrous hydroxide

in the presence of dissolved oxygen would be oxidized to the insoluble ferric hydroxide. Any zinc and lead compounds would also tend to be largely removed as a result of precipitation along with the iron and aluminum which would form a heavy flocculent precipitate. The sludge would be deposited in the retention ponds, the clear neutralized supernatant overflowing to the natural drainage.

Chemical requirements will depend upon the quantity and the chemical nature of the waste. Table 24 summarizes such data, together with cost estimates in general terms.

Table 24 Comparative Cost and Quantities of Various Chemicals Considered in Connection with Neutralizing Acid Mine Waste.

	Assumed Purity	lbs./million gallons per p.p.m. acidity* removed	Estimated cost/ million gallons per p.p.m. ** acidity removed
Hydrated lime, $Ca(OH)_2$	90%	7.0	$0.035 - 0.07
Quicklime, CaO	88%	5.4	$0.027
Limestone, (as $CaCO_3$)	95%	9.0	$0.009
Soda Ash, Na_2Co_3	98%	9.2	$0.184
Caustic Soda, NaOH	100%	6.8	$0.136

* Acidity expressed in terms of sulphuric acid, H_2SO_4.

** Hydrated lime at $.005 to $.01/lb. Quicklime at $.005/lb. Crushed limestone (10 mesh) at $.01/lb. Soda ash at $.02/lb. Caustic soda at $.02/lb. F.O.B. mines.

The effective use of crushed limestone, is dependent upon use of a finely ground material (90% 200 mesh), thorough mixing, and adequate aeration. The latter two factors are important in connection with the use of other chemicals.

Chemical treatment by quicklime or powdered limestone offers a possible solution to the mine waste pollution problem for those mines not handling large quantities of highly acid water. Where quantities and acidities are high, such treatment would be expensive.

Figure 6 is included for convenience in estimating the amounts of hydrated lime, quicklime and limestone required for treating various quantities of mine water of varying acidity.

As a result of acid neutralization the hydroxides of iron and aluminum will precipitate. These will have considerable bulk. Figure 7 will enable the quantities of hydroxides to be estimated on a dry tonnage basis for various volumes of waste (MGD) and various concentrations of iron and aluminum. The volume of sludge per ton of dry solids may be approximated on the basis of 92.5% moisture content.

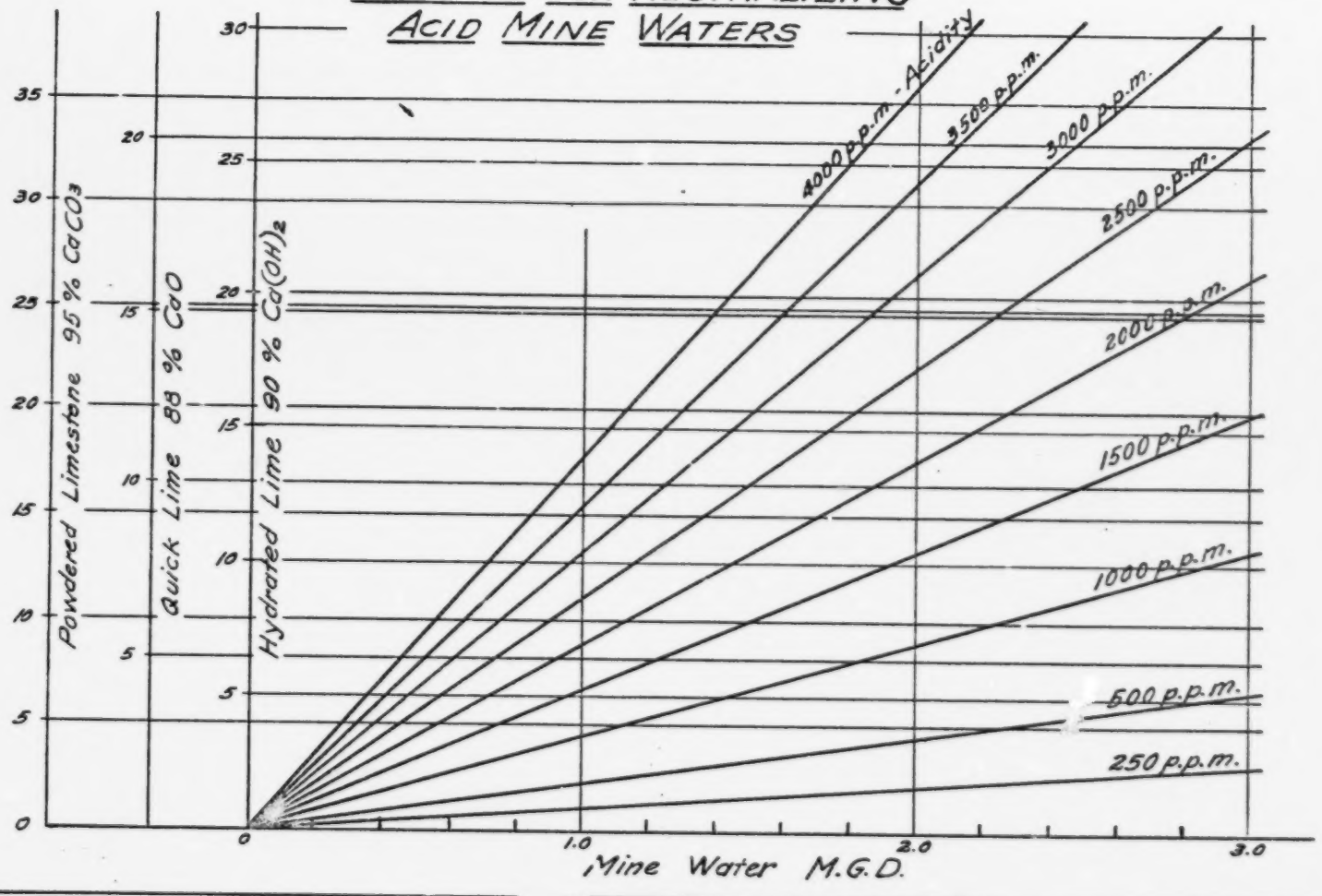
Table 22 indicates that the ratio of ferric to aluminum hydroxide would be roughly 3 to 1. Therefore the average specific gravity of the dry mixed hydroxides would be 3.2.

The volume of a 92.5% sludge containing one ton of ferric and aluminum hydroxides is computed to be 405 cubic feet. Since the volume of a high moisture content sludge varies nearly inversely as the percentage of dry solids, sludge having a moisture content of 85% would occupy about 200 cubic feet per ton of dry hydroxides; with 96.25% moisture content, about 800 cubic feet. Based on 92.5% moisture content the following table will give an approximation of the quantities of sludge that would result from complete precipitation of the iron and aluminum in the various mine waters:

Mines Tributary to	Tons/day $Fe(OH)_3$	Tons/day $Al(OH)_3$	Daily volume 92.5% Sludge Cubic Foot	Acre-Foot
Neosho River	1.19	0.47	700	.016
Spring River	10.8	3.13	6,000	.14

FIG. 6

QUANTITIES OF CHEMICALS REQUIRED FOR NEUTRALIZING ACID MINE WATERS



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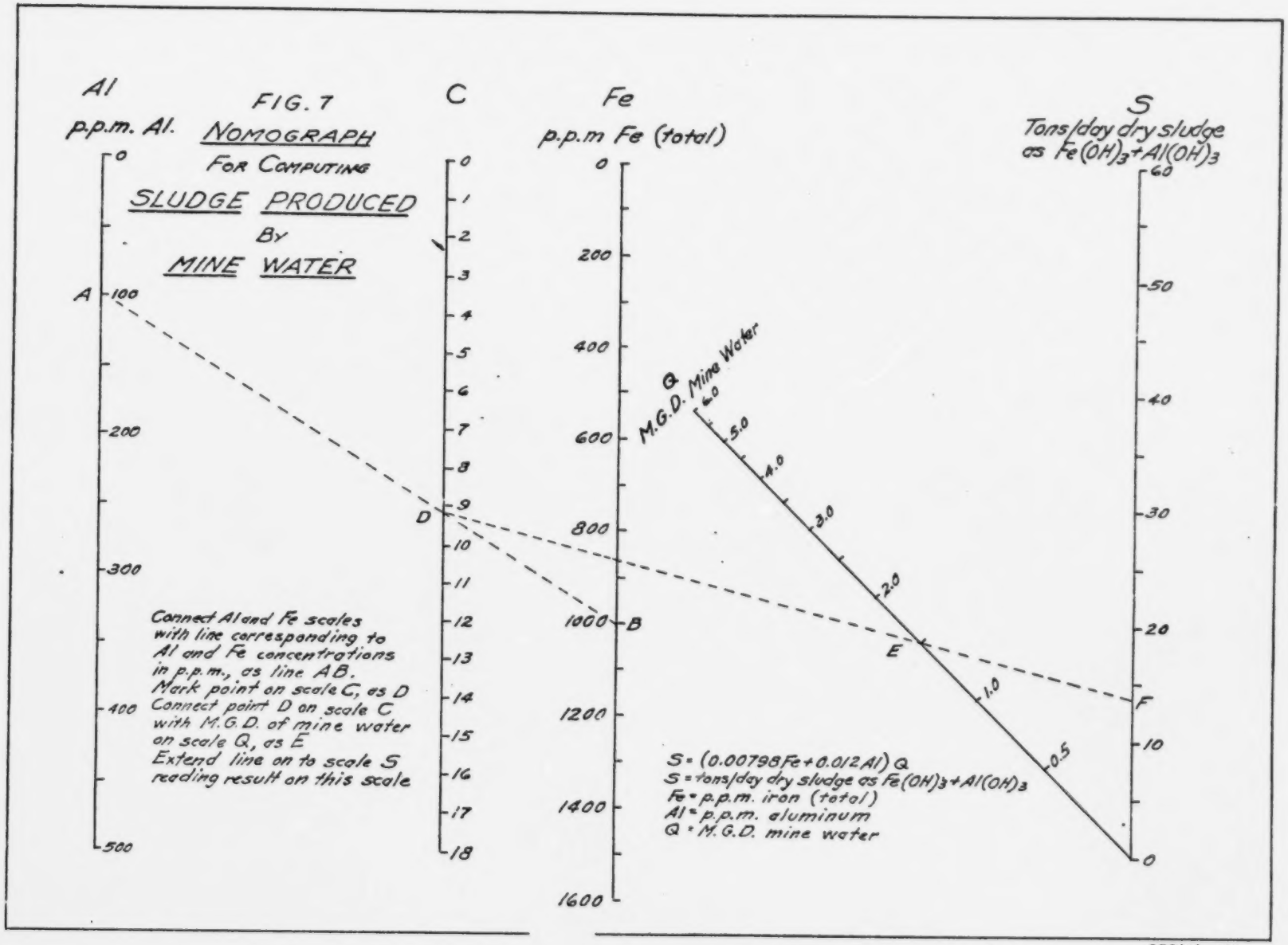

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These data, offered as a guide to what might be expected, suggest the magnitude of the sludge removal and disposal problem.

(c) Neutralizing Mine Waste by Surface Water Alkalinity- Where acid wastes are discharged to normal surface streams the natural alkalinity of the diluting water serves as a neutralizing and precipitating agent just as lime or limestone. The diversion of surface waters to neutralizing-precipitation ponds for mine waste treatment offers promise for eliminating the formation of iron and aluminum hydroxide sludge in the streams.

Practical application of this method of treatment has been considered by one mining company. The tentative plan involves discharging the mine water to a system of impounding basins and mixing with proper amounts of normal stream water diverted from a nearby river. Following neutralization of acidity and precipitation of iron and aluminum hydroxide the impounded water will return to the stream.

Figure 8 shows the relation between quantity of mine waste, acidity in p.p.m. as H_2SO_4, and the amount of surface water of varying alkalinity needed for neutralization.

Complete precipitation of the iron will depend on its ox-

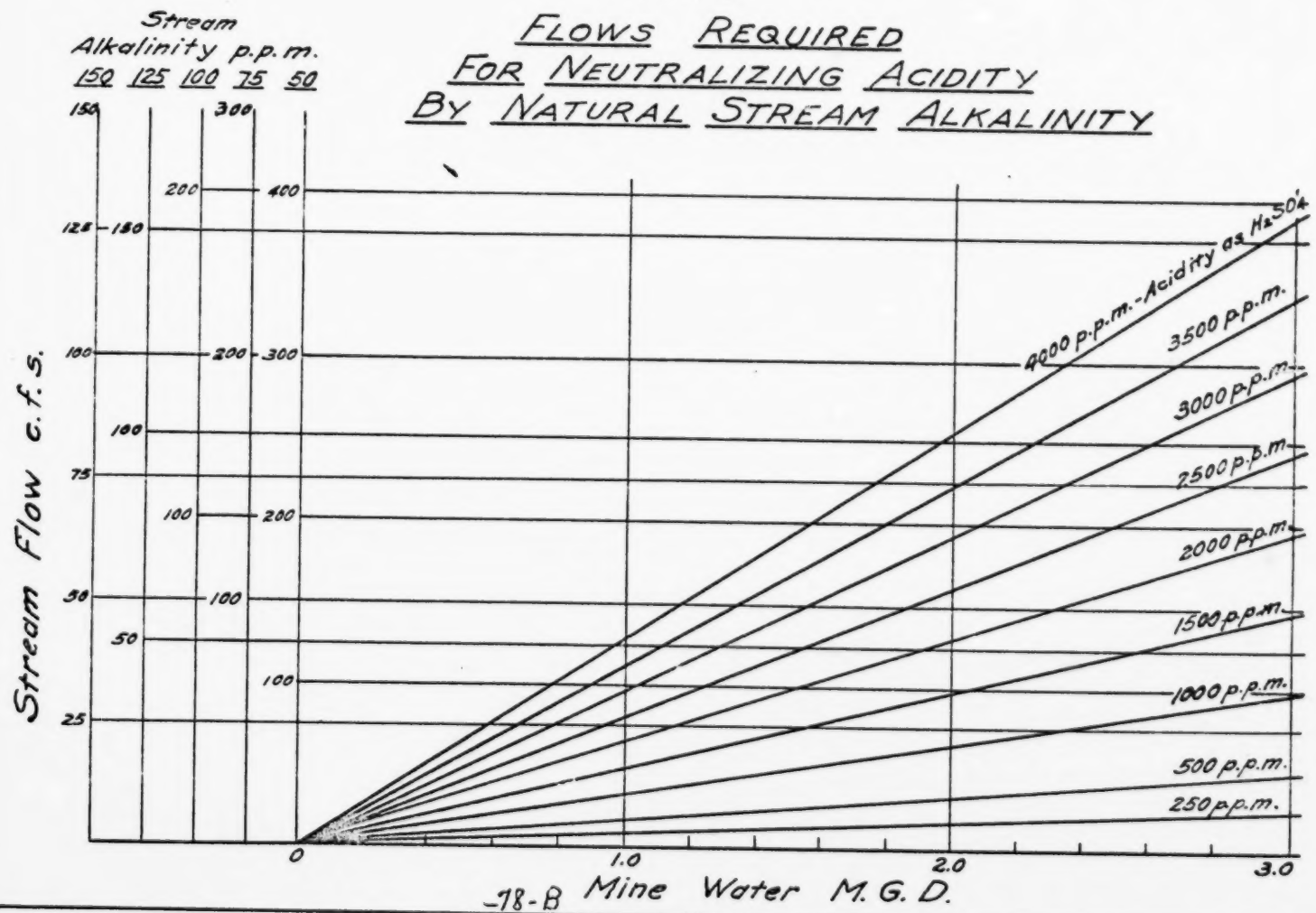
idation by dissolved oxygen. Turbulent flow of the mine water in open channels will provide aeration and the dilution water will furnish additional oxygen.

The sludge problem in this instance will be similar to that previously discussed except that the volume of iron and aluminum sludge will be increased by the silt load of the water diverted from the stream.

With sufficient settling the return water from the settling ponds should be clear and relatively free of suspended matter. Unless a large excess of dilution water is used the pH in the pond will be rather low as a result of carbon dioxide. Settling pond effluent will lower the alkalinity of the receiving stream an amount equivalent to the acidity of the mine water plus the dilutional effect of the mine water. Thus utilization of natural alkalinity for neutralization only accomplishes iron and aluminum removal. However, in the case of Spring River this is the chief problem. In the case of Tar Creek, a small stream, this method of handling wastes might have to be supplemented, in some instances, by additional chemical treatment in order to preserve the stream alkalinity balance. A preliminary estimate given for such a project to serve several mines

FIG. 8

FLOWS REQUIRED FOR NEUTRALIZING ACIDITY BY NATURAL STREAM ALKALINITY



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tributary to Spring River is as follows:

Excavation 20,000 cu. yd.	$20,000
Masonry dams, 1,500 cu. yd.	22,000
Rip rap retarding dams 1,500 cu.yd.	15,000
Pipe and wooden conduits 3,500'	7,000
Gates, Engineering, Contingencies	16,000
Total	$80,000

Treatment works of this nature should be designed to minimize the possibility of high water passing through the settling system and flushing the deposited sludge into the stream.

Of the methods available for treating and disposing of mine wastes this method, possibly supplemented in some cases by chemical treatment, appears to offer the most possibilities. However, before any substantial investment is made in works for applying this method it is recommended that pilot studies be made on a scale sufficient to be representative of all factors involved.

(d) (e) Diversions of Surface Water and Sealing - Measures taken to minimize the quantity of water entering active or inactive mines will reduce the pollution problem. Inasmuch as draw-down in one mine affects the tributary area, pumping of an active mine will invariably draw water from surrounding mines.

Since oxygen from the air is essential for acid formation in water in contact with pyrite and marcasite sealing the shafts of any completely worked out mine or worked out section of an active mine to exclude oxygen (air) would also tend to reduce the acidity of water pumped from adjacent active mines.

Appendix A

Stream Flow Data

Estimates of monthly discharge at the three reservoir sites have been prepared by the U. S. Engineer Department. The following five paragraphs and three tables are abstracted from the Hydrology Appendix of the U. S. Engineer Department report.

Estimates of discharge. - Estimates of discharge have been made at Marion dam site on the Cottonwood River; Council Grove, and Iola dam sites on the Grand (Neosho) River. The following methods were used in estimating flows at the several sites:

Revision and extension of flows at Iola, Kansas, U. S. Geological Survey Gage. - A rating curve applicable to the entire period of record at Iola (October 12, 1917, to date) on the Grand (Neosho) River, and a stage relation curve between the U. S. Weather Bureau and U. S. Geological Survey gages at Iola for the period 1906-1921 were obtained from the U. S. Geological Survey. Published flows before October 1937, were obtained from rating curves based on data now considered to be incomplete, and such flows have been revised by use of the latest discharge rating curve. In order to extend the flows at Iola, stages from the U. S. Weather Bureau records from October 1908, to October 11, 1917, inclusive, were applied to the stage relation curve and the flows obtained from the discharge rating curve.

Extension of flows at the Elmdale gage. - There are available 17 complete years of record on the Cottonwood River from the gages at Elmdale (May 9, 1922, to June 30, 1932) and Cottonwood Falls (April 8, 1932, to date). In the computations outlined below, the station at Elmdale was used for its entire period of record and the station at Cottonwood Falls was used from July 1, 1932, to date. In

extending flows at Elmdale from May 1922, back to October 1919, the runoff per cent at Iola was computed for each month and the same runoff per cent was used for the same month at Elmdale, the runoff being computed from weighted rainfall. Where the rainfall above the two stations for a given month varied by more than 20 per cent, further adjustment was made. Base flow at Elmdale was obtained by reducing the base flow at Iola in direct proportion to the drainage areas involved.

Flows at Marion, and Council Grove Dam sites. - From the 20 years of monthly flows obtained at Elmdale and Cottonwood Falls, flows at Marion and Council Grove dam sites were estimated by reducing the flows at Elmdale and Cottonwood Falls in direct proportion to the drainage areas involved.

Flows at Iola Dam site. - Flows at Iola dam site were estimated by reducing flows at the Iola gage in direct proportion to the drainage areas involved.

In addition to the data shown in Tables A, B and C, the published records in Water Supply Papers of the U. S. Geological Survey of flows at Iola and Parsons on the Grand (Neosho) River and at Elmdale and Cottonwood Falls on the Cottonwood River were used in the study of low flow periods.

Table A Estimated Monthly and Annual Flows in Acre-Feet at Council Grove Dam Site.

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1920	97	249	136	175	155	542	1,790	1,420	986	2,610	1,020	2,140	11,320
1921	736	641	869	1,450	650	2,460	2,800	2,610	5,820	423	1,140	1,060	20,660
1922	276	62	91	102	453	18,160	30,740	10,570	1,630	4,980	903	374	68,340
1923	381	7,380	1,230	830	607	883	874	6,550	43,690	7,570	1,210	3,690	74,900
1924	4,370	2,010	1,580	1,210	1,350	9,100	8,470	12,180	2,520	1,570	2,030	762	47,150
1925	534	272	208	551	650	995	1,960	738	4,830	1,190	267	2,090	14,280
1926	303	415	228	149	296	371	3,450	932	638	194	352	11,750	19,080
1927	17,770	2,400	1,210	374	1,120	3,620	29,850	17,770	25,970	3,420	34,710	9,150	147,400
1928	3,350	1,670	1,480	971	1,970	4,660	14,030	4,830	19,930	11,040	6,020	954	70,900
1929	150	19,560	5,560	7,160	5,100	3,200	8,930	14,900	12,040	37,620	11,020	1,020	128,300
1930	1,640	3,620	1,700	1,250	3,910	934	4,300	17,620	5,320	536	1,210	6,330	48,370
1931	774	2,500	1,150	665	527	1,010	2,040	1,280	5,700	388	282	624	16,940
1932	189	15,990	4,420	2,100	2,100	3,620	1,480	2,690	6,160	21,810	1,580	1,140	63,280
1933	627	689	812	725	467	575	2,180	4,120	249	699	369	1,180	12,690
1934	158	70	164	170	111	248	743	1,110	301	91	15	826	4,010
1935	279	1,050	265	241	204	244	206	20,150	13,670	1,360	357	175	38,200
1936	1,880	1,620	808	639	377	350	185	4,170	251	44	38	199	10,560
1937	1,740	242	225	2,100	9,200	1,550	1,260	2,080	1,830	1,890	616	3,480	26,210
1938	122	192	247	230	178	327	1,070	35,170	12,690	2,760	4,780	1,660	59,430
1939	500	1,790	618	540	402	980	1,080	784	4,010	620	5,570	112	17,010
Mean	1,890	3,120	1,150	1,080	1,490	2,690	5,870	8,080	8,410	5,040	3,670	2,440	44,930

Table B Estimated Monthly and Annual Flows in Acre-Feet at Marion Dam Site.

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1920	80	205	112	144	127	446	1,470	1,170	813	2,150	837	1,760	9,310
1921	607	528	716	1,200	535	2,030	2,310	2,150	4,790	349	938	870	17,020
1922	228	51	75	84	373	14,960	25,330	8,710	1,340	4,100	744	308	56,300
1923	314	6,080	1,010	684	500	728	720	5,400	36,000	6,240	996	3,040	61,710
1924	3,600	1,650	1,300	1,000	1,110	7,500	6,980	10,040	2,080	1,290	1,670	628	38,850
1925	440	224	171	454	536	820	1,620	608	3,980	984	220	1,730	11,790
1926	250	342	188	123	244	306	2,840	768	526	160	290	9,680	15,720
1927	14,640	1,980	994	308	926	2,980	24,600	14,640	21,400	2,820	28,600	7,540	121,400
1928	2,760	1,380	1,220	800	1,620	3,840	11,560	3,980	16,420	9,100	4,960	786	58,430
1929	1,770	16,060	4,580	5,900	4,200	2,640	7,360	12,280	9,920	27,000	9,080	842	101,600
1930	1,350	2,980	1,400	1,030	3,220	770	3,540	14,520	4,380	442	998	5,220	39,850
1931	638	2,060	950	548	434	832	1,680	1,050	4,700	320	232	514	13,960
1932	156	13,180	3,640	1,730	1,730	2,980	1,220	2,220	5,080	17,980	1,300	938	52,150
1933	516	568	670	598	386	474	1,800	3,400	206	577	304	974	10,470
1934	130	58	136	140	92	204	612	919	248	75	13	681	3,310
1935	230	863	218	198	168	201	170	16,610	11,270	1,120	294	144	31,490
1936	1,550	1,340	666	527	311	288	153	3,440	207	37	31	164	8,710
1937	1,440	200	186	1,730	7,590	1,280	1,040	1,710	1,510	1,550	508	2,870	21,610
1938	100	158	204	190	147	270	883	29,000	10,460	2,270	3,940	1,370	48,990
1939	412	1,480	509	445	331	808	888	646	3,300	511	4,590	93	14,010
Mean	1,560	2,570	950	890	1,230	2,220	4,840	6,660	6,930	3,950	3,030	2,010	36,840

Table C Estimated Monthly and Annual Flows in Acre-Feet at Iola Dam Site.

Water Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Annual
1920	2,130	2,860	2,750	3,280	2,210	23,460	23,140	19,240	16,040	34,290	26,260	96,370	252,000
1921	11,480	7,570	12,280	22,080	10,440	53,320	34,920	71,020	96,920	9,210	16,750	28,330	374,300
1922	3,960	900	1,260	1,670	4,050	275,100	531,700	134,200	29,690	135,400	44,230	3,870	1,166,000
1923	2,260	53,650	9,800	6,430	4,320	15,590	9,960	112,700	573,200	172,600	13,550	9,910	984,000
1924	64,010	27,310	28,660	16,000	26,410	82,510	63,120	110,800	41,270	53,070	56,590	33,340	603,100
1925	24,320	15,340	7,240	32,090	23,640	12,980	106,800	28,180	99,430	10,990	1,690	10,870	373,600
1926	13,620	49,280	8,890	10,930	7,860	8,640	110,300	40,110	20,240	2,710	14,180	605,800	892,600
1927	434,900	48,910	34,940	30,560	33,360	117,900	853,400	251,000	314,300	42,480	306,800	84,040	2,553,000
1928	226,600	19,090	16,760	20,780	25,540	63,580	125,800	45,600	190,200	136,700	70,440	19,840	1,261,000
1929	22,750	611,900	171,800	172,400	65,710	74,750	218,900	307,400	169,000	292,700	76,620	30,100	2,214,000
1930	9,560	22,630	9,480	6,030	41,910	13,590	28,000	205,600	70,880	8,210	6,800	25,850	448,600
1931	5,980	23,140	15,030	6,650	7,120	21,010	50,870	54,080	45,840	7,300	1,780	6,090	244,900
1932	1,910	305,000	80,320	49,410	36,420	39,190	49,340	41,030	146,800	262,100	21,650	9,160	1,042,000
1933	5,010	3,810	4,930	4,890	3,480	6,750	75,870	117,100	7,350	9,630	14,640	26,410	279,900
1934	8,930	1,530	5,130	2,420	1,610	4,760	26,210	88,220	18,930	1,590	310	3,740	163,400
1935	5,490	46,950	9,660	18,300	8,630	4,660	6,490	428,000	468,800	29,750	12,250	52,270	1,091,000
1936	98,900	246,500	37,260	32,630	10,580	8,910	3,890	51,950	7,430	780	58	4,270	503,200
1937	24,360	3,270	8,360	31,420	135,200	72,500	56,520	114,900	103,500	15,340	8,900	43,790	618,100
1938	1,740	1,500	1,920	1,720	2,380	34,680	57,940	848,100	401,500	45,640	45,110	20,110	1,462,000
1939	4,540	11,730	5,810	5,220	3,980	10,040	22,570	28,530	24,990	13,090	30,960	2,150	163,600
Mean	48,620	75,140	23,610	23,750	22,740	47,200	122,800	154,900	157,300	64,180	38,480	55,820	834,500

Appendix A